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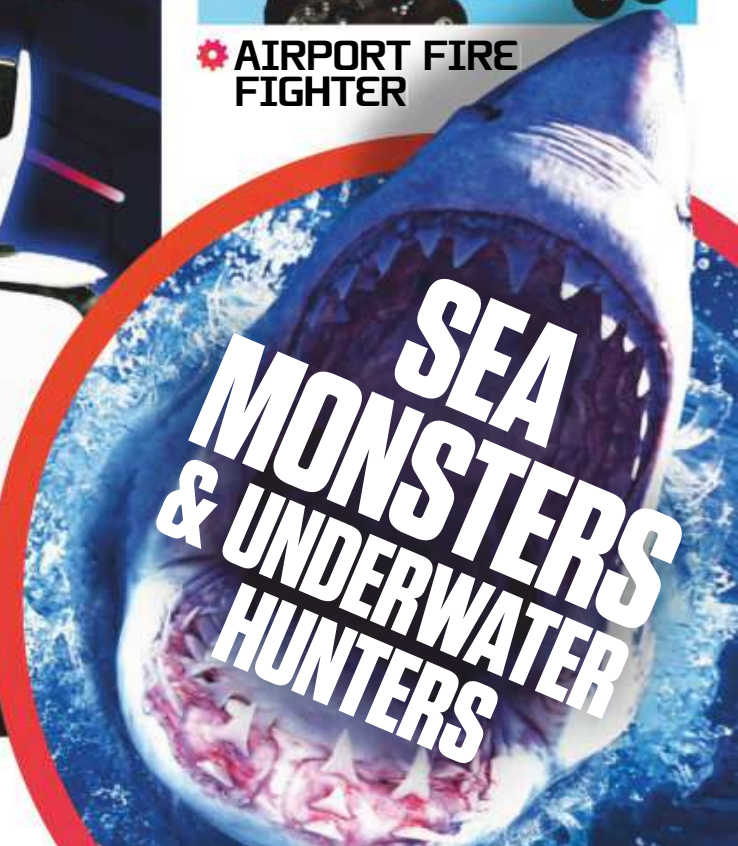


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# WELCOME

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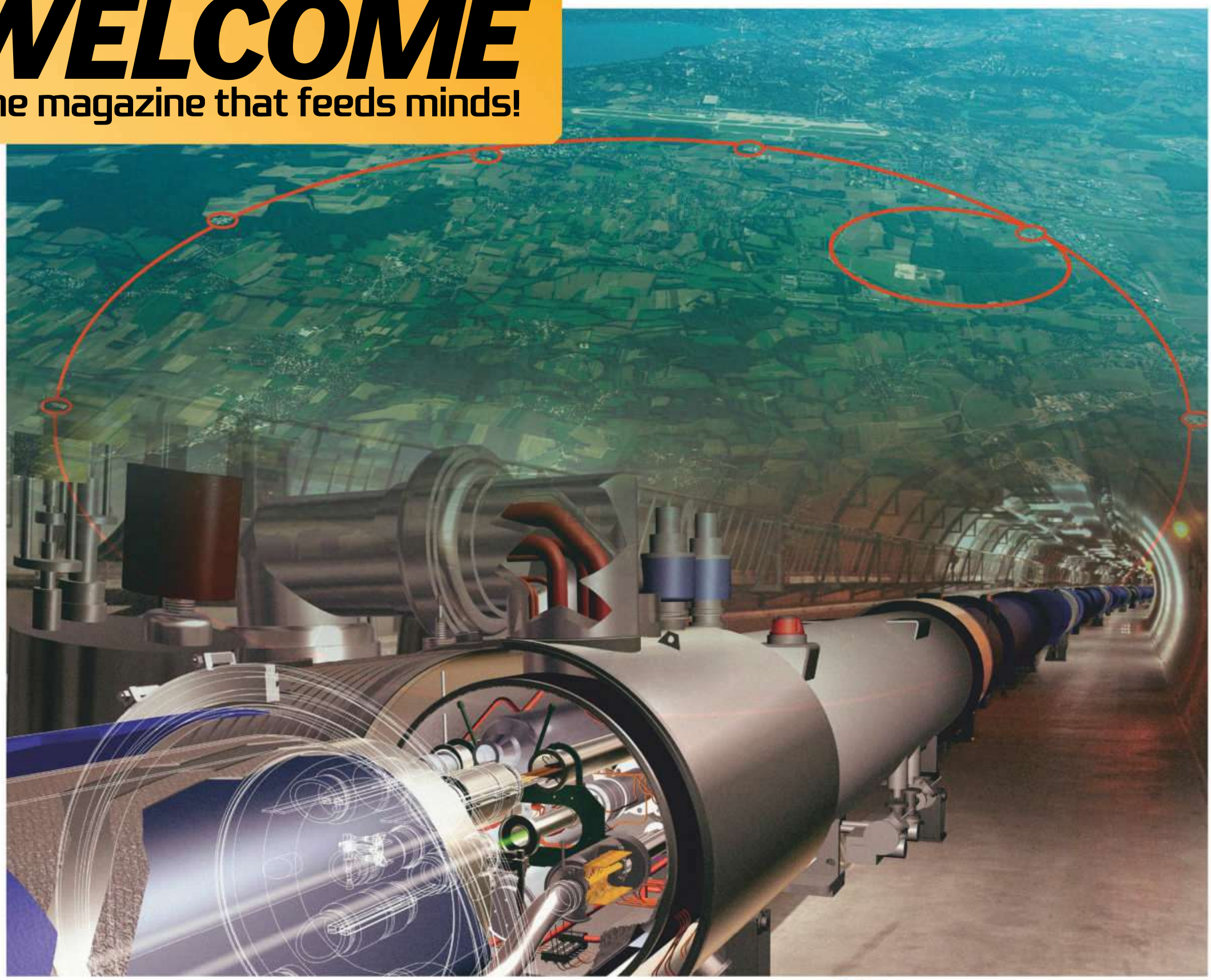

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*"As part of the opening ceremony of the 2021 Olympics, satellites will launch a human-made meteor shower"*

**2021's hottest sci and tech to watch out for, page 20**

It's hard to believe the advances in science and technology we've made in the last ten years alone, but 2021 will see the culmination of years of hard work and innovation pay off. The opening ceremony of the delayed Summer Olympics will feature a synthetic meteor shower, 5G and VR will come together to offer a myriad of possibilities in augmented and virtual experiences, the James Webb Space Telescope will allow us to peer deeper into the universe than ever before and much more. Nature has its own events planned too, including two solar eclipses and a brood of cicadas millions-strong that emerges only once every 17 years.

Enjoy the issue!

**Ben** Editor

## Meet the team...

**Nikole**
**Production Editor**
Humans have dug deep into the ground, but we haven't reached the mantle of our planet yet. Dive into the depths on page 28.

**Scott**
**Staff Writer**
From Saturn's two-faced satellite to Jupiter's volcanic companion, meet the weirdest moons in our Solar System on page 80.

**Baljeet**
**Research Editor**
Well-equipped for potential disasters at airports all over the world, get inside the biggest, fastest fire-fighting vehicle on page 58.

**Duncan**
**Senior Art Editor**
The body is capable of repairing itself after an accident or injury, even patching up broken bones. Learn how it heals itself on page 62.

**Ailsa**
**Staff Writer**
The transatlantic slave trade was the largest forced migration in history. Find out how these horrific ordeals ended on page 40.

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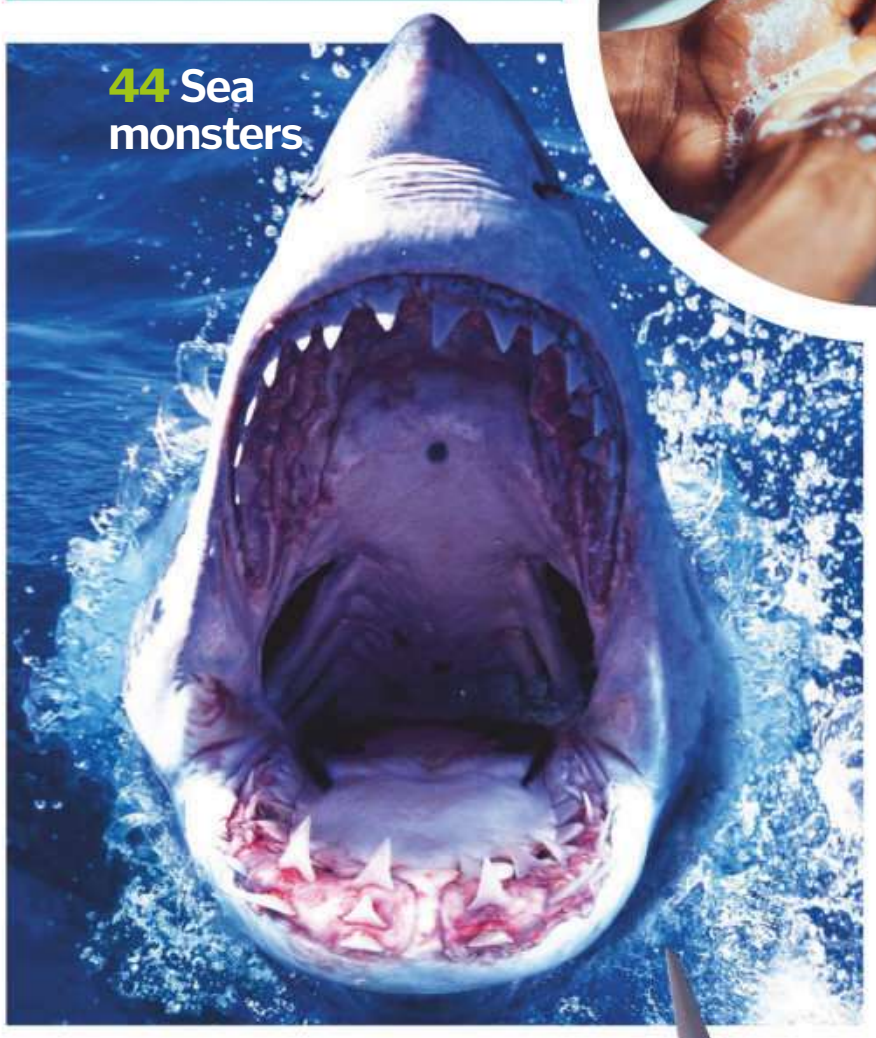


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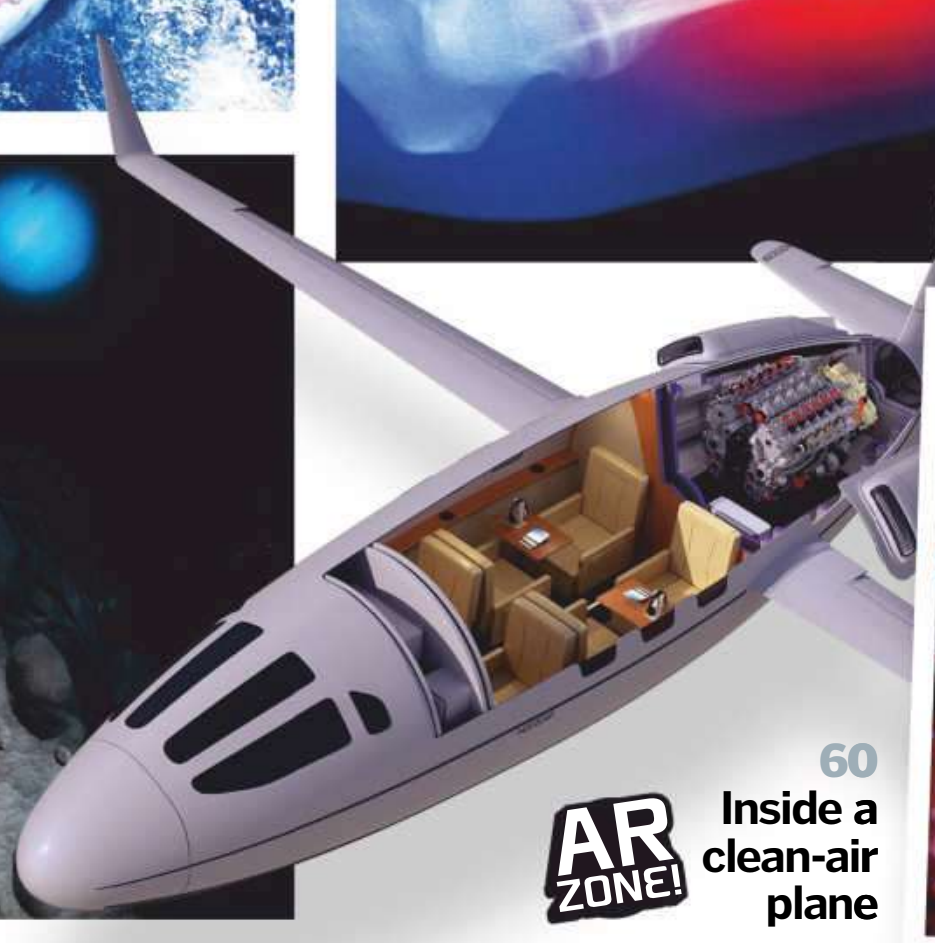


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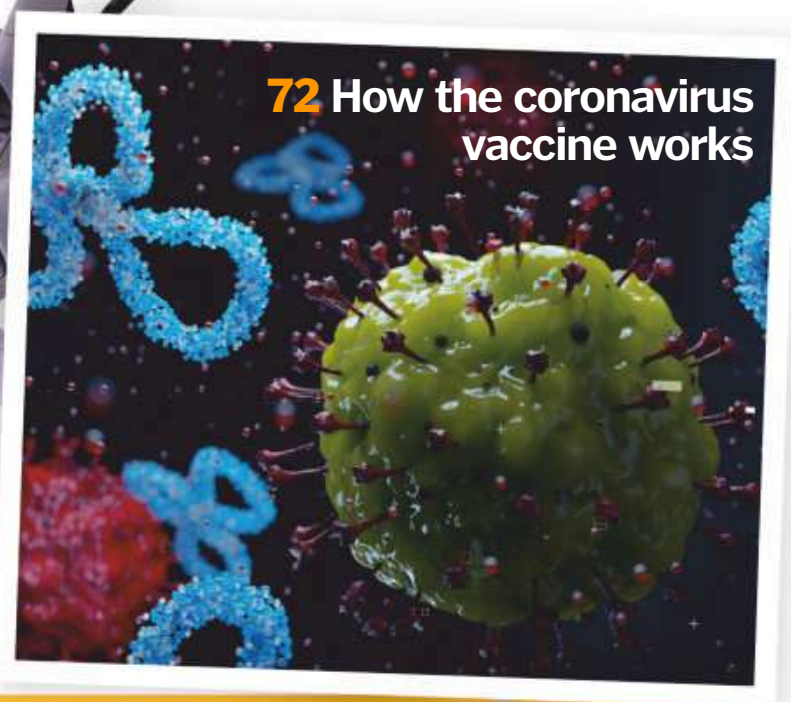


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## AR ZONE!

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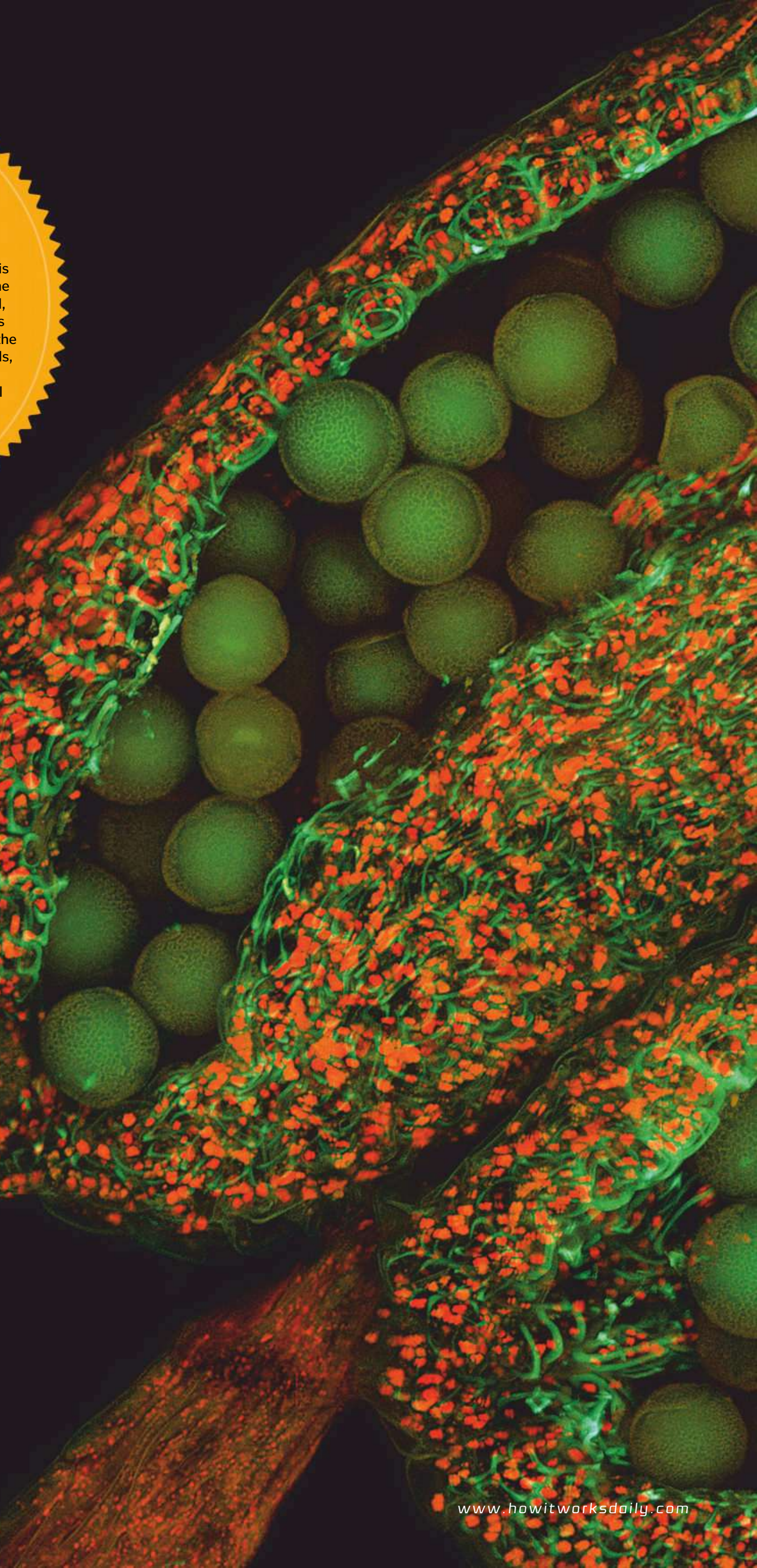
# INSIDE THE POLLEN STORE

This is a thale cress plant's reproductive organ, called an anther. Within the anther are chambers called microsporangia that manufacture and store grains of pollen, seen in this image as green spheres. Pollen is released from the anther when a pollinator, such as an insect or bird, brushes up against the organ, which in turn opens small pores for the pollen to escape. Upon release the pollen, which contains the plant's male 'sperm' cells, falls from the anther to the female reproductive organs, including the plant's ovary, for successful reproduction and the development of seeds. This image was captured using confocal microscopy, using laser-focused fluorescent light to reveal magnified images.



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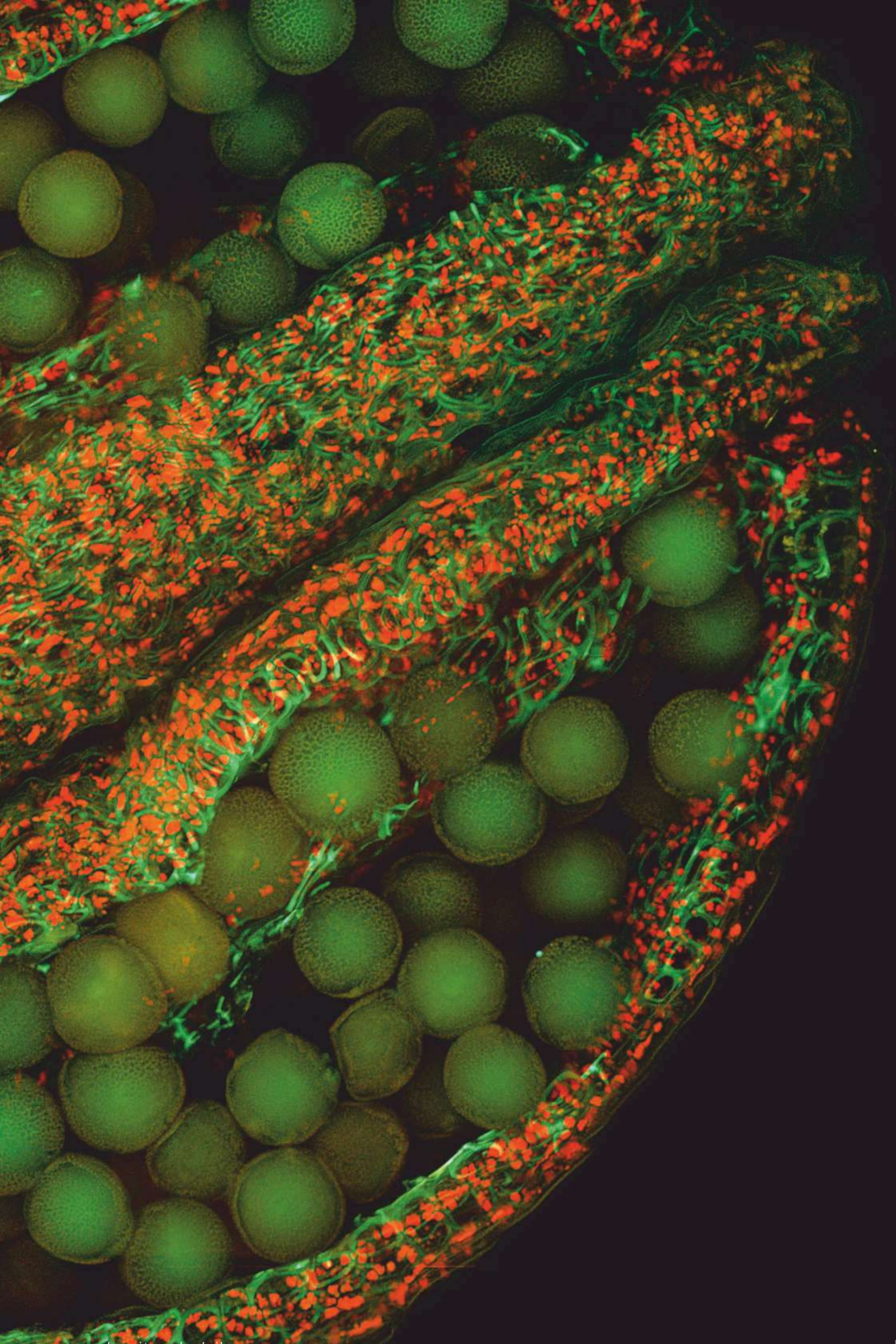

# ON TOP OF THE WORLD

Imagine glancing down and seeing the whole world at your feet. It's a sight not many have seen, but one astronaut Franklin R. Chang-Díaz is all too familiar with. In this image, taken in 2002, Chang-Díaz is performing a spacewalk – as part of the STS-111 mission – outside the International Space Station. The mission began with the installation of a power and data grapple fixture for the station's robotic arm. The fixture was installed halfway up the station's space frame, called the P6 truss, which supports the large solar array for power production. Chang-Díaz completed seven Space Shuttle missions between 1986 and 2002 and shares the record for the most spaceflights with Jerry Ross.

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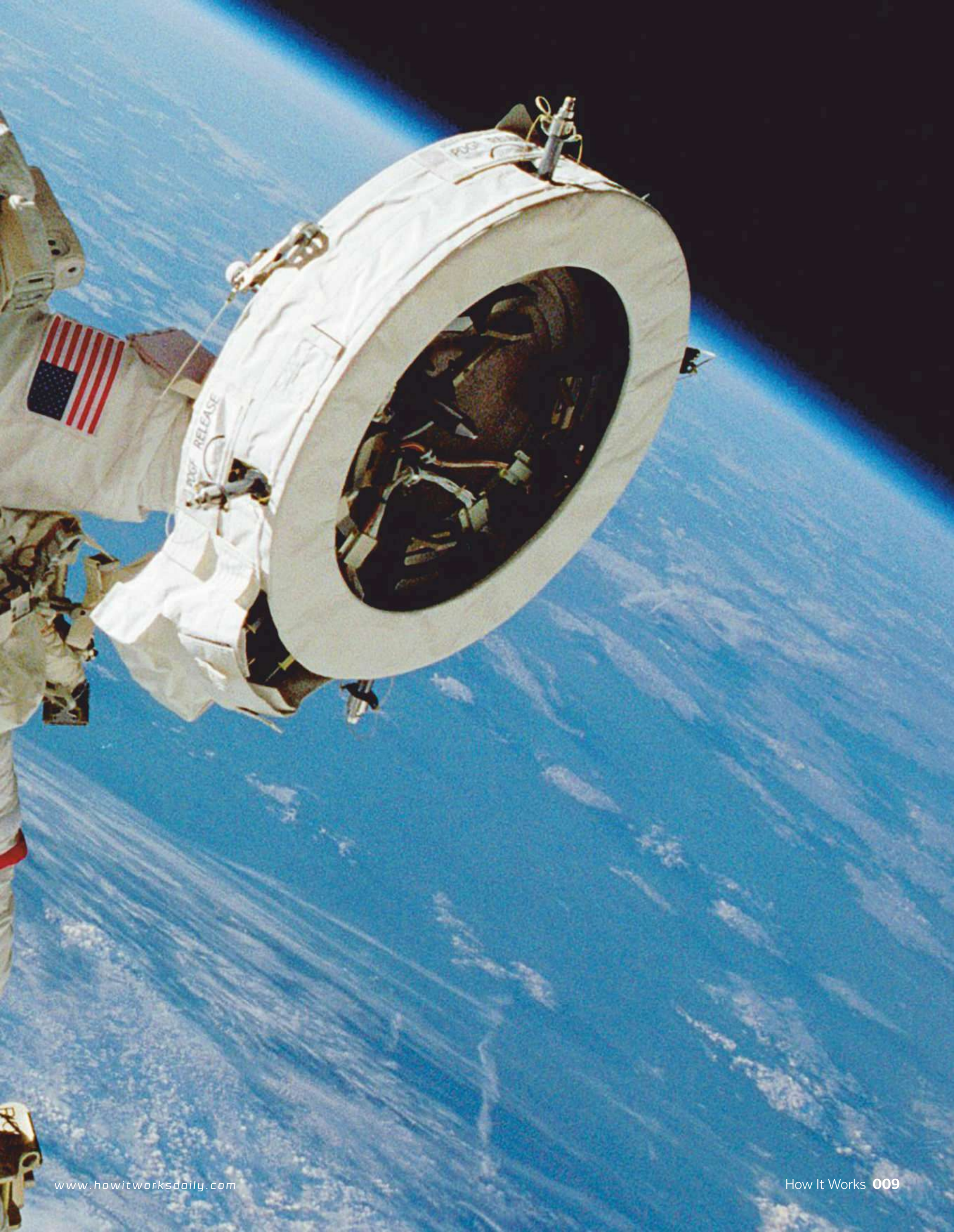

# GLOBAL EYE

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A globular cluster glows in the Large Magellanic Cloud, one of the Milky Way's satellite galaxies

SPACE

# Newfound collision may be the biggest in Milky Way history

Words by **Brandon Specktor**

**The Milky Way contains more than 100 billion stars, but it didn't come by them all honestly. At least a dozen times over the last 12 billion years, the Milky Way collided with a neighbouring galaxy and devoured it, swallowing up that neighbour's stars and mixing them into an ever-growing stew of pilfered suns.**

**With each new galactic merger, the shape, size and motion of our galaxy changed forever, ultimately becoming the iconic spiral we recognise today. A recent study has attempted to unwind that spiral. Using artificial intelligence (AI) to match distinct clusters of stars by their ages, motions and chemical compositions, the team found evidence of five large-scale galactic mergers, each involving 100 million stars or more, dating back more than 10 billion years, including one ancient collision that has never been described before.**

**This newfound crash with the so-called Kraken galaxy not only helps fill in the Milky Way's mysterious family tree, but could also help astronomers piece together what our galaxy looked like in its earliest days. "The collision with Kraken must have been the most significant merger the Milky Way ever experienced," said Diederik Kruijssen, an astronomer at the University of Heidelberg in Germany. "The merger with Kraken took place 11 billion years ago, when the Milky Way was four-times less massive [than today]. As a result, the collision must have truly transformed what the Milky Way looked like at the time."**

**Kruijssen and his colleagues used computer simulations to analyse all the known globular clusters – old, dense spheres of up to 1 million stars that all formed around the same time as each other – within the Milky Way. Our galaxy hosts at least 150 of these clusters, which astronomers believe are 'fossils' of the ancient galaxies that the Milky Way gobbled up over its long and hungry history.**

**The researchers trained an AI algorithm to identify globular clusters based on the shared properties of stars, at first running it on thousands of simulated galaxies. Once the algorithm was able to accurately predict the formation, evolution and destruction of globular clusters in those imaginary galaxies, the team set their AI on ours.**

**Using data obtained by the Gaia space probe – which has given us the most complete map of the Milky Way – the algorithm analysed the ages, movements and chemical compositions of known globular clusters in our galaxy in order to recreate the cosmic mergers that landed them there. The team's analysis accurately predicted four known mergers in the Milky Way's past. The Kraken may have been the largest and oldest galactic collision in the Milky Way's history. The merger occurred when the Milky Way was only a fraction of its current size, and may**

© NASA, ESA, and Martino Romaniello European Southern Observatory, Germany

have added to our galaxy 13 globular clusters that are still identifiable today.

This newfound merger is only one small piece of the puzzle. Because the road to galaxy formation is strewn with collisions like these, it's likely that many more small-scale mergers also contributed to the Milky Way we know today. Astronomers suspect that at least 15 other mergers may be lurking in our galaxy's past that each involved 10 million stars or more, and their remnants are just waiting to be found in our galaxy's globular guts.

Astronomers have about 3 or 4 billion years to figure it out. Following that, another galaxy-altering merger will occur when our neighbour Andromeda – currently 2.5 million light years away – and the Milky Way will inevitably collide. Isn't that always the way: just when you think you know a galaxy, it goes and changes on you again.

Ice seems to go on forever at Humboldt Glacier in northwest Greenland

© Getty

PLANET EARTH

# Primeval Greenland lake found under mile of ice

Words by **Stephanie Pappas**

Scientists have discovered an ancient lake bed buried under more than a mile of ice that may hold secrets to Greenland's past climate. The lake formed when northwest Greenland was ice-free, sometime between hundreds of thousands or even millions of years ago. Given Greenland's rapid melt today, the lake could reveal something about the Arctic's future as the ice caps shrink.

"This could be an important repository of information in a landscape that right now is totally concealed and inaccessible," said Guy Paxman, a researcher at Columbia University's Lamont-Doherty Earth Observatory. "We're working to try and understand how the Greenland ice sheet has behaved in the past. It's important if we want to understand how it will behave in future decades." Paxman and his colleagues discovered the lake using data from instruments that use radar to penetrate beneath the icy surface to measure topography; much of the data came from NASA's Operation IceBridge.

*"The lake basin sits 1.1 miles below the surface of the ice"*

The lake basin sits 1.1 miles below the surface of the ice and stretches over 2,700 square miles, the size of Rhode Island and Delaware combined. At its deepest point the lake would have extended about 250 metres down. The researchers mapped 18 streambeds that would have flowed into the lake from the north, as well as an outlet that would have drained it to the south. This ancient water system is nothing but sediment now, and scientists don't know when it last held water. Previous research suggests Greenland's ice has advanced and retreated at various points over the last million years. There may have also been ice-free stretches going back over the past 30 million years.

The depth of the sediments in the lake suggests it is between hundreds of thousands and millions of years old. To get more specific than that, scientists would have to drill beneath the ice into the lake sediments to study them directly.

The lake may have been formed when an ancient fault pulled the Earth apart, creating a depression, or it may have been a bowl carved out by a retreating glacier. Drilling into the lake bed might also provide clues to the future. The lake bed may contain traces of certain chemicals or fossils that could reveal more about Greenland's past climate. Scientists could then compare these past conditions with the changing conditions in the Arctic today. There are no current plans to drill into the lake bed, but such a feat would be possible.

SPACE

# Birth of a magnetic star seen for the first time

Words by **Rafi Letzter**

Two neutron stars slammed together far away from Earth. The energy of their collision lit up their corner of the sky with a brief flash of gamma radiation, followed by a softer, longer-lasting glow across the electromagnetic spectrum. Peering into that fading light, researchers spotted an unusual infrared signal, possibly the first-ever recorded signature of a newborn cosmic behemoth, a magnetar.

A magnetar is a neutron star with an unusually strong magnetic field. Astronomers have spotted magnetars elsewhere in the universe, but they've never before seen one being born. Researchers suspect this because of an unusual pattern of flashing light. First there was a short, ultrabright burst of gamma radiation (GRB). Then there was a longer-lasting, glowing 'kilonova', a telltale sign of neutron stars colliding. And that glow was much brighter than usual, suggesting a phenomenon astronomers had never seen before.

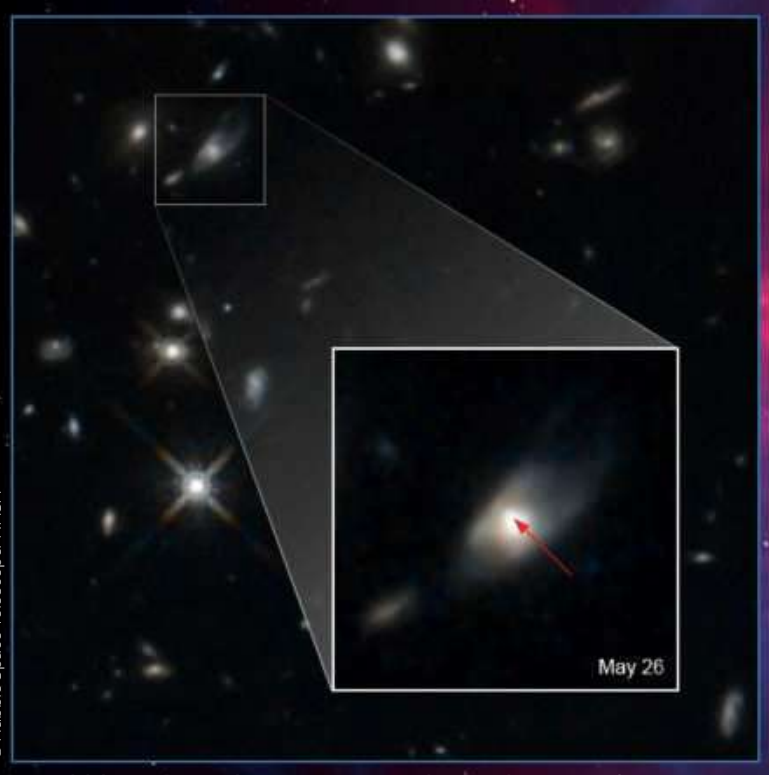
To detect neutron star collisions, scientists look for both short GRBs and longer-lasting light sources from the collision. Under normal circumstances, said Wen-fai Fong, a Northwestern University astrophysicist, the glow left over from a neutron star collision has two parts: there's short-lived 'afterglow', which last for a couple of days and results from material speeding away from the collision and slamming at high velocity into the dust and gas between stars. And then there's the 'kilonova' glow of stirred-up particles swirling around the collision site.

The recent event, called GRB 200522A, had a visible kilonova, but something was different. Scientists know from their models and previous observations how bright a kilonova should look. GRB 200522A was much brighter, particularly in the infrared part of the electromagnetic spectrum.

"I can count on my hands the number of kilonovae that have been discovered from short gamma-ray bursts," said Fong. "But this was ten times brighter than any of those." To explain why the kilonova was so bright, the researchers needed to figure out what new ingredient was present in the aftermath of the neutron star collision. "We settled on a very large magnetar," Fong said. Like a whirling figure skater bringing their arms close to their body, the two orbiting neutron stars combined to form a faster-spinning magnetar. Its powerful magnetic fields acted like the blades of a blender, stirring up the already-energised kilonova particles and making them glow even brighter. But there are other explanations, too.

One possibility is a 'reverse shock'. Two waves of the fast-moving particles from the afterglow might have slammed into each other. If conditions were just right, that crash might mimic a newborn magnetar. Similarly, some unexpected, decaying radioactive particles in the kilonova might have made GRB 200522A glow brighter. But Fong said both of these scenarios are unlikely.

Assuming it is a magnetar, Fong said, future observations should reveal radio emissions from the distant site. One day the James Webb Space Telescope should be able to peer further into short GRB sites, revealing still-unseen details of these collisions.

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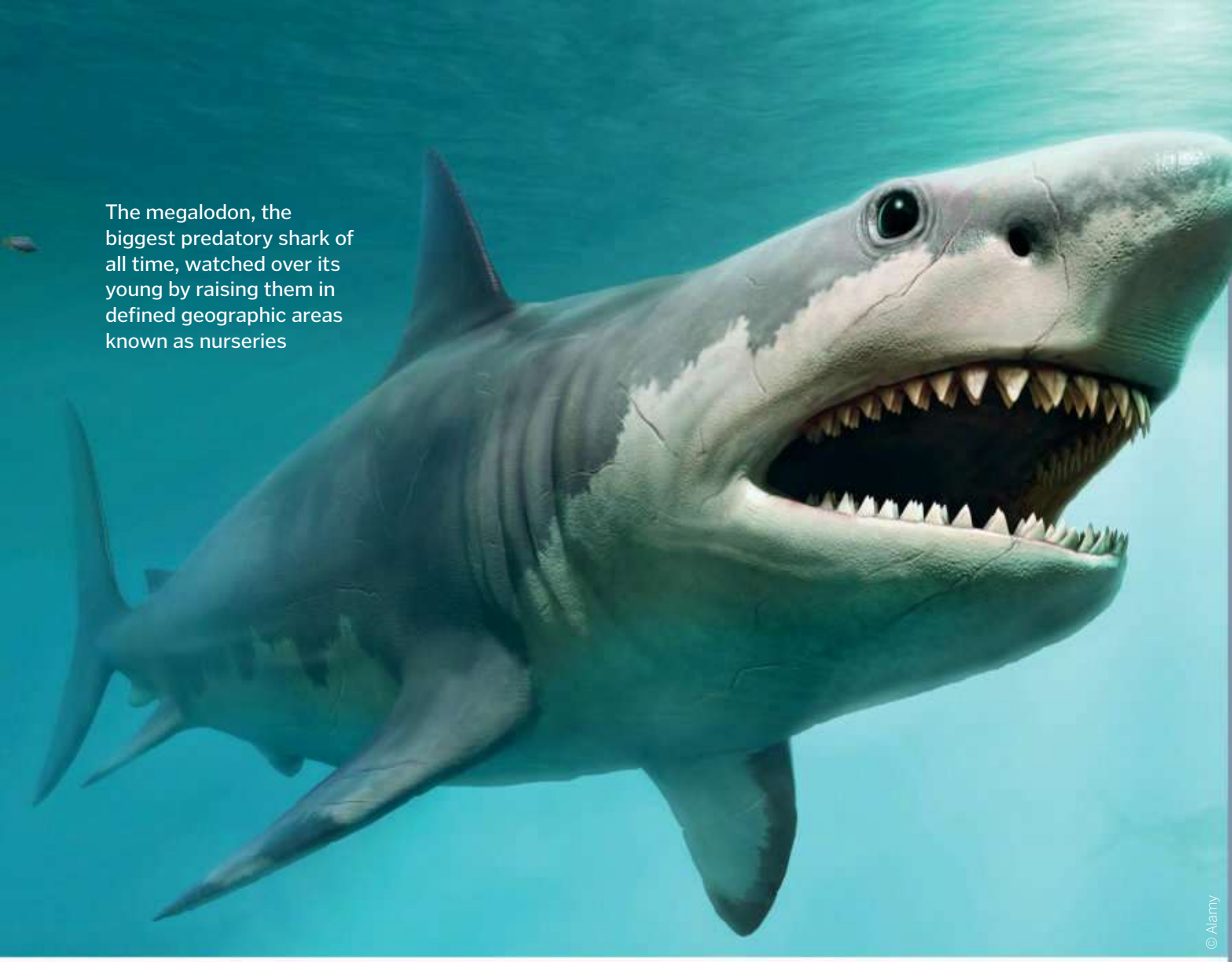
A Hubble Space Telescope image shows the part of the sky where the unusual light pattern came from, indicating the birth of a magnetar

A computer-generated illustration of a magnetar, a type of neutron star with a strong magnetic field © Getty



The megalodon, the biggest predatory shark of all time, watched over its young by raising them in defined geographic areas known as nurseries

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ANIMALS

# Megalodon nurseries reveal the monster shark's soft side

Words by **Mindy Weisberger**

The enormous, extinct shark megalodon probably doesn't make you think of parenting and play dates. But a growing body of evidence suggests that these massive marine predators nurtured their babies by raising them in nurseries, and scientists have added five potential megalodon nurseries to the list. These baby-shark grounds are showing up all over. Scientists reported in 2010 that they had identified a megalodon nursery in Panama. Recently another team of researchers described a new megalodon nursery site in northeastern Spain; fossils of fully grown sharks and youngsters were found together, with most of the fossils belonging to juveniles and newborns.

Those same scientists also analysed data from eight other sites from 16 million to 3 million years ago, where *Otodus megalodon* fossils were plentiful. They evaluated the body sizes of individual sharks to determine the ratio of juveniles to adults, and named four additional nursery sites. The results suggest that megalodon adults commonly raised their young in nursery areas, where the little shark babies would be protected until they were able to fend for themselves against other ocean predators. It also raises the possibility that the decline of available nursery sites may have contributed to the giant shark's extinction.

*O. megalodon* is estimated to have measured up to 15 metres in length, making it the biggest predatory shark that ever lived. Most megalodon fossils date to about 15 million years ago, and the giant fish vanished from the fossil record about 2.6 million years ago.

For the recent study, the researchers investigated 25 teeth belonging to *O. megalodon* from the Reverté and Vidal quarries in Spain's Tarragona province. They used tooth crown height to estimate body size and to identify which of the sharks were babies: very young sharks, likely about one month old, that measured about four metres long, and older juveniles measuring up to 11 metres in length.

The scientists then used algorithms to model and compare the ratio of *O. megalodon* juveniles to adults at eight other sites across "a wide geographical area" that included the Atlantic, Caribbean and Pacific basins. They determined five potential nurseries "with higher densities of individuals with estimated body lengths within the typical range of neonates and young juveniles," including the site in Panama that had been described in 2010.

PLANET EARTH

# Coral tower taller than the Empire State Building discovered

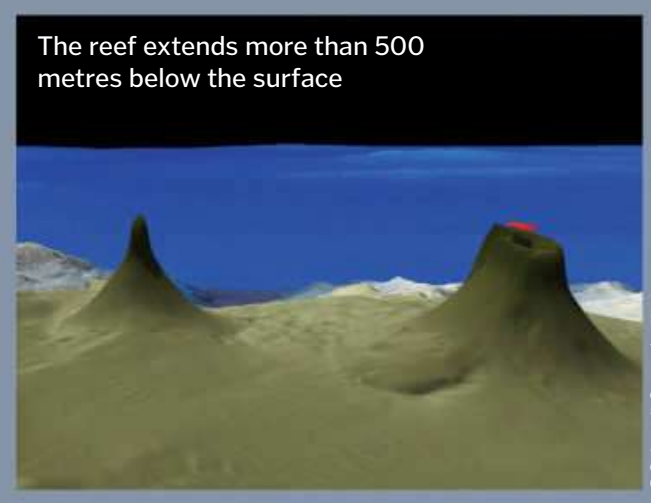
Words by **Brandon Specktor**

**An underwater research vessel has stumbled upon a gargantuan coral reef, standing like a monolithic tower off the coast of Northern Australia. According to scientists at the Schmidt Ocean Institute, who are conducting a year-long expedition of the ocean around Australia, this newly discovered reef stands more than 500 metres high from base to tip, making it taller than the Empire State Building.**

**The newly discovered reef is part of the Great Barrier Reef, the single longest coral reef in the world, spanning more than 1,400 miles along the northeastern coast of Australia. This new branch of the massive underwater structure stands freely from the rest of the reef, making it the first detached coral reef discovered in the area in 120 years.**

**"To find a new half-a-kilometre-tall reef in the well-recognised Great Barrier Reef shows how mysterious the world is just beyond our coastline," said Jyotika Virmani, executive director of the Schmidt Ocean Institute. Scientists aboard the research vessel Falkor discovered the new reef on 20 October 2020 while constructing a 3D map of the ocean floor. The lonely tower of coral, which the team described as 'blade-like', measures one mile wide at its base before rising up to its peak roughly 40 metres below the sea's surface.**

**Using a remotely operated vehicle (ROV), the team explored the new reef's surface, revealing a rainbow menagerie of corals and underwater fauna.**



The reef extends more than 500 metres below the surface

© Schmidt Ocean Institute

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TECH

# Stratolaunch starts building hypersonic plane

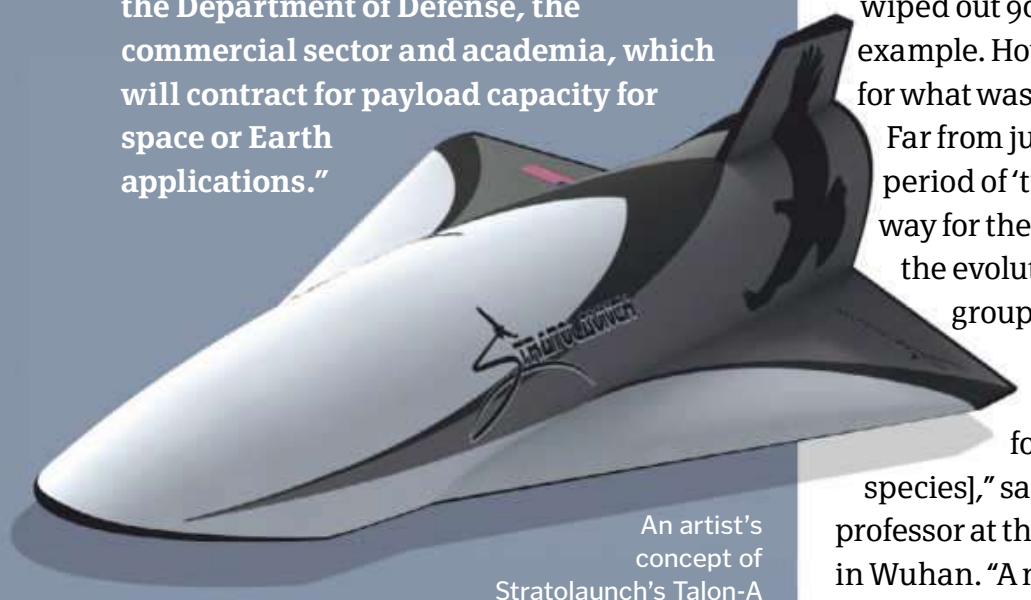
Words by **Elizabeth Howell**

**Stratolaunch has begun construction on a prototype hypersonic vehicle designed to launch from the world's biggest aeroplane. Pictures the company shared show a prelude of the sleek Talon-A reusable hypersonic vehicle coming together in a manufacturing facility. "The upper skin layup tool and prototype upper skin are giving us a peek at what's to come. One. Step. Closer," Stratolaunch tweeted.**

**In March 2020, Stratolaunch announced it would pivot its services to building, testing and operating vehicles that fly at Mach 5, five-times faster than the speed of sound. "Our hypersonic testbeds will serve as a catalyst in sparking a renaissance in hypersonic technologies for our government, the commercial sector and academia," CEO W. Jean Floyd said. Talon will be 8.5 metres long with a mass of 2,700 kilograms, and will fly as fast as Mach 6.**

**In October, Stratolaunch said testing on its first engine was complete, courtesy of a partnership agreement with propulsion company Ursa Major Tech. Stratolaunch also signed an agreement with Draper, a decades-old engineering nonprofit, to provide guidance, navigation and control software for the hypersonic vehicle.**

**"Under the multi-year contract, Draper will design, develop and deliver a guidance, navigation and control system for the Stratolaunch reusable hypersonic vehicle," said Draper representatives. "The vehicle is designed for use by government, the Department of Defense, the commercial sector and academia, which will contract for payload capacity for space or Earth applications."**



An artist's concept of Stratolaunch's Talon-A hypersonic test vehicle

© Stratolaunch

The Triassic Period ended with a million-year rain storm that paved the way for the reign of the dinosaurs, a new paper claims

© Alamy

PLANET EARTH

# Triassic Period ended with a 'lost' mass extinction

Words by **Brandon Specktor**

Before the dawn of the age of dinosaurs, a heavy rain descended upon the supercontinent Pangaea, and it kept raining for more than a million years. This epic rainy spell, known now as the Carnian Pluvial Episode (CPE), occurred roughly 233 million years ago and was a stark shift from the typically arid conditions of the late Triassic Period. But storms weren't the only change Earth was facing. Recent fossil evidence suggests the CPE was a major extinction event, driven by volcanic eruptions and climate change, that resulted in the deaths of one-third of all marine species, plus a significant number of plants and animals.

This 'lost' extinction event doesn't quite reach the death toll of the five major mass extinctions typically discussed by the scientific community – the Permian-Triassic extinction event, which occurred just 20 million years earlier, may have wiped out 90 per cent of living species, for example. However, the CPE isn't just important for what was lost, but also for what was gained. Far from just a period of death, the CPE was a period of 'turnover', effectively paving the way for the dominion of the dinosaurs and the evolution of many terrestrial animal groups that still roam Earth today.

"A key feature of the CPE is that extinction was very rapidly followed by a big radiation [of new species]," said Jacopo Dal Corso, a geology professor at the China University of Geosciences in Wuhan. "A number of groups that have a central role in today's ecosystems appeared or diversified for the first time in the Carnian [an age within the Triassic that lasted from 237 to 227 million years ago]."

Those groups include modern coral reefs and plankton in the oceans, as well as the appearance of land-based fauna such as frogs, lizards, crocodilians, turtles and a diverse new swath of dinosaurs, who would thrive for the next 150 million years. Conifers also made their first appearance during the Carnian, further planting the roots of many modern ecosystems and inviting the 'dawn of the modern world'.

But what brought on the world-changing rain in the first place? It's hard to say for certain, but the authors of a new study believe the answers may lie in a continent-spanning lava field known as the Wrangellia Terrane, which runs for thousands of miles across the western coast of modern-day Canada. This massive igneous province was laid down by violent volcanism during the Carnian, and overlaps, at least partially, with the CPE.

Prior studies estimate that those mighty eruptions released at least 5,000 gigatonnes of carbon into the atmosphere – that's hundreds of times more than annual global emissions today – likely kicking off the extreme climate change that followed. The world became significantly more humid, heavy rains became the norm, the oceans acidified and entire species died in droves, paving the way for strange new plants and animals to slowly take over. However, much more work is needed to understand the full scope of the CPE and its possible triggers.

HISTORY

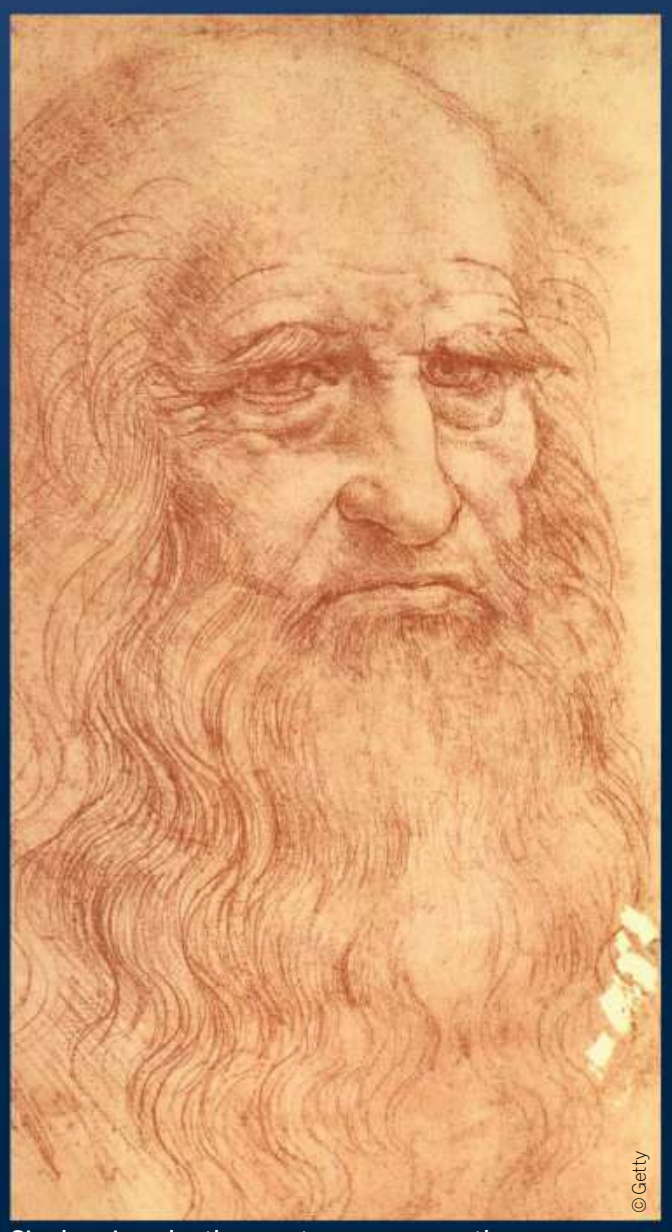
# Hidden bacteria and fungi discovered on da Vinci's drawings

Words by **Rafi Letzter**

**Leonardo da Vinci is famous for his elaborate, nuanced artworks and advanced technological ideas. But recent research has revealed another level of complexity to his drawings: a hidden world of tiny life forms. The findings could help build a microbiome 'catalogue' for artwork. Each of the pieces had a unique-enough collection of microbes that researchers could identify it again later purely from a study of its microscopic biology. And the drawings' microbiomes had enough key elements in common to help researchers spot counterfeits based on differences in their microbiomes, or even authentic drawings that had been stored in different conditions over the centuries. The researchers also showed that da Vinci's drawings had a significantly different microbiome than expected, with lots of bacteria and human DNA, likely a consequence of centuries of handling by art restorers and other people. Microbes known to make paper degrade over time were also present, showing why those restorers' efforts had been necessary.**

**Researchers examined the microscopic biological material, living and dead, in seven of the master's 'emblematic' drawings and found an unexpected diversity of bacteria, fungi and human DNA. Most of that material probably landed on the sketches well after da Vinci's death, so the majority of DNA likely comes from other people who have handled the drawings over the centuries and not the polymath himself. But the newfound biological materials do have a story to tell.**

**The biggest surprise was the high concentration of bacteria in the drawings, especially when compared with fungi. Past studies have shown that fungi tend to dominate the microbiomes of paper objects such as these drawings, but in this case an unusually high amount of bacteria from humans and insects – likely flies that pooped on the paper at some point – were present. "Altogether the insects, the restoration workers and the geographic localisation seem to all have left a trace invisible to the eye on the drawings," the researchers said. "[But] it is difficult to say if any of these contaminants originate from the time when Leonardo da Vinci was sketching its drawings."**



Six drawings by the master were recently revealed to host complex microbiomes

**Most of that DNA likely came from people who have restored the work, starting in the 15th century. The team has not analysed the genetic material in the level of detail necessary to see who specifically it might have come from.**

**The researchers used a new tool called nanopore, a genetic-sequencing method that quickly breaks down and analyses genetic material, to make the detailed study of the different biological materials. The same researchers have studied artistic microbiomes in the past to determine how statues that were recovered from smugglers had been stored while they were in hiding.**

**Going forward, the researchers said, this technique could reveal new details of the histories of even well-studied artworks.**

For more of the latest stories, head to **livescience.com**



HISTORY

# 100 mummies found at Egyptian burial site

Words by **Owen Jarus**

The number of mummy-filled coffins found in a series of burial shafts at Saqqara in Egypt keeps growing. At the start of September 2020, a team of archaeologists had found 13 coffins with mummies inside. By the beginning of October that number had risen to 59, and now the number is over 100. People are "asking how many coffins did we find. The answer is I don't know yet," said Mustafa Waziri, the secretary-general of Egypt's Supreme Council of Antiquities.

Inside the burial shafts, the team also found 40 statues depicting the deity Ptah-Soker. This deity is an amalgamation of Ptah, who was the god of Memphis, and Soker, who was the god of Saqqara. Archaeologists also found 20 wooden boxes showing depictions of Horus, an Egyptian sky god with a falcon head. Additionally, two wooden statues inscribed with the name Phnomus were unearthed, though the researchers are still trying to figure out who that person was in antiquity. Numerous shabti figures were also found. Ancient Egyptians believed that shabtis acted as servants for the deceased in the afterlife.

The various finds date back to between roughly 712 and 30 BCE. During this time period, ancient Egypt was occupied and controlled by foreign groups such as the Assyrians, Persians and Greeks. At times Egypt would regain its independence, only to lose it to another foreign power. Excavations continue at the site, and the archaeologists expect to find more coffins filled with mummies and other artefacts, said Khaled El-Enany, Egypt's antiquities minister.

© Getty
The colours on the mummy-filled coffins are remarkably well preserved, despite the passage of over 2,000 years

# WISH LIST

The latest **next-gen** gadgets

## The Sero QLED 4K UHD HDR Smart TV

© Samsung

■ Price: **£1,399 / $1,999**
**www.samsung.com**

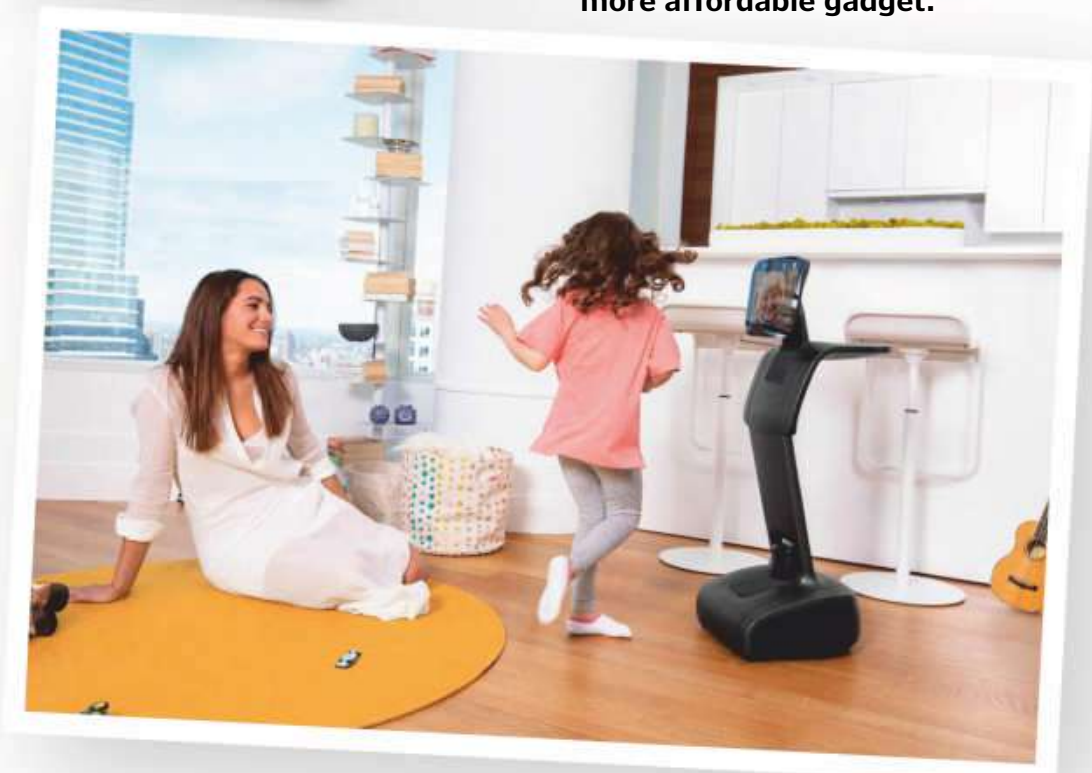
**It might look like a giant smartphone, but the Sero TV by Samsung is the revolutionary futuristic TV that moves to fit your content. View live programming, streaming services and social media content in either portrait or landscape mode. This high-tech television is made to work with your smartphone and can mirror your mobile in a tap, casting its content on screen in an instant. The built-in AI also claims to upscale content to a 4K resolution from any source.**

## Temi: the Personal Robot

© Temi

■ Price: **$3,999 (approx. £2,998)**
**www.robotemi.com**

**Are we one robot closer to living like the Jetsons? With the creation of this home-assistant robot, Temi, we might be. This video-orientated robot uses its built-in AI to recognise its owner, follow them on request or move autonomously around your home. This mechanical assistant has a whole host of features, including making video calls and constructing shopping lists, and can pair with your Alexa for instant information and control over other smart home devices. Currently robots such as Temi come with a hefty price tag, but in time they could become a common and more affordable gadget.**



© NextMind

## NextMind Dev Kit

■ Price: **$399 (approx. £299)**
**www.next-mind.com**

**NextMind has been marketed as the world's first commercially available non-invasive brain-computer interface that allows you to control your devices by thought alone. This device uses machine learning to decode brain activity from the visual cortex of the brain via its built-in sensors. This means that while you're focusing on an object or menu option on a screen or in a VR headset, the device can recognise it and perform an action. The development kit is currently only available to preorder, and centres around use in gaming and entertainment, but in time could open up a new way to interact with technology globally.**

# Ambassador Interpreter

Price: **from $99 (approx. £74)**
www.waverlylabs.com

**Language barriers may become a thing of the past with the creation of devices like the Ambassador Interpreter by Waverly Labs. In a nutshell, these wireless devices record the voice of one speaker, upload the audio to the cloud, translate it into a chosen language and then send the translation to another earpiece. Up to four Ambassador Interpreters can be used together, paired with a single smartphone, for group conversations. These mobile interpreters can capture speech from 2.5 metres away, boast a six-hour battery life and can translate 20 languages.**

© Waverly Labs

# LG PuriCare™ Wearable Air Purifier

Price: **HK$1,180 (approx. £113.50)**
www.lg.com

**Wearing a face mask has quickly become a part of normal life during this global pandemic, but manufacturers such as LG are giving them an upgrade. Taking the opportunity to technologically transform the simple mask, the PuriCare™ Wearable Air Purifier uses a series of filters, dual fans and respiratory sensors to provide fresh and clean air to the wearer. The mask also comes with a case equipped with built-in UV-LED lights to kill germs. This personal air device is not yet available in the UK or US, but in time we could see next-gen masks like this in the future.**

© LG

# Wearbuds

Price: **$179 (approx. £134)**
www.myaipower.com

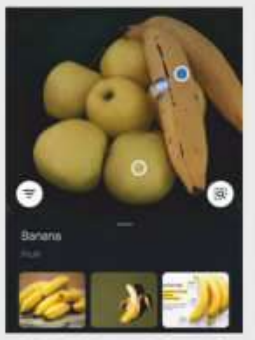
**Wearbuds combine the ease of wireless earbuds and the analytics of a fitness tracker. These earbuds are housed in the face of a wrist charging unit and boast 13 hours of playback on a single charge. Wearbuds offer premium sound quality and noise isolation while being splash and sweat-proof. The wearable charging unit also doubles as a sleep and fitness tracker to follow your running distance, exercise performance and heart rate.**

© Aipower

# APPS & TOOLS

## Google Lens

Developer: **Google LLC**
Price: **Free / Google Play/ App Store**




Gather information about what's in front of you with this easy-to-use app. From translations to plant identification, it's jam-packed with features.

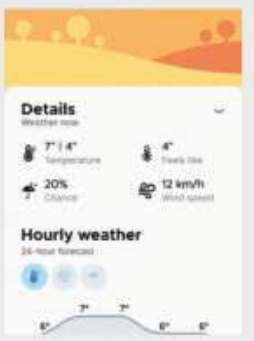
## Mondly

Developer: **ATi Studios**
Price: **Free / Google Play / App Store**

This AR app is the next generation of language learning. More than 30 languages are available to learn through games, lessons and practice.

## Overdrop

Developer: **39ninety**
Price: **Free / Google Play / App Store**




This hyperlocal weather and radar app collates information from a range of forecast providers to give you the most up-to-date information.

## Augment – 3D Augmented Reality

Developer: **Augment**
Price: **Free / Google Play / APP Store**

This lets you place any home goods in a virtual room. It also allows business owners to create images of their products for users to engage with.

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GREEN HYDROGEN REVOLUTION
LARGE HADRON COLLIDER WAKES UP

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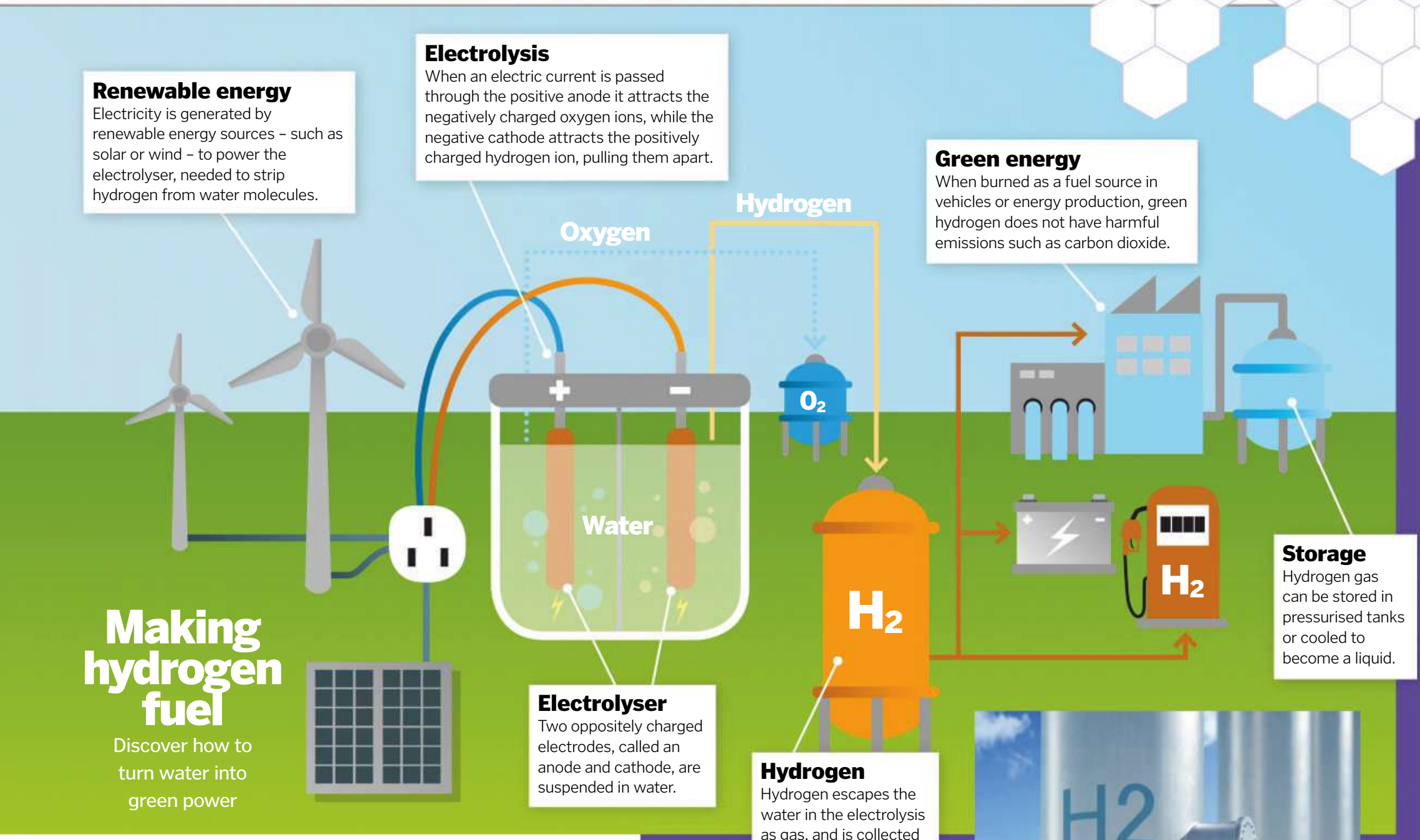
# 2021's HOTTEST SCI & TECH TO WATCH OUT FOR

## WHAT DISCOVERIES, INNOVATIONS AND SCIENTIFIC EVENTS CAN WE EXPECT TO SEE?

Words by **Scott Dutfield**


Renewable energy
Electricity is generated by renewable energy sources – such as solar or wind – to power the electrolyser, needed to strip hydrogen from water molecules.
Electrolysis
When an electric current is passed through the positive anode it attracts the negatively charged oxygen ions, while the negative cathode attracts the positively charged hydrogen ion, pulling them apart.
Green energy
When burned as a fuel source in vehicles or energy production, green hydrogen does not have harmful emissions such as carbon dioxide.
Hydrogen
Oxygen
$O_2$
Water
$H_2$
$H_2$
Storage
Hydrogen gas can be stored in pressurised tanks or cooled to become a liquid.
Electrolyser
Two oppositely charged electrodes, called an anode and cathode, are suspended in water.
Hydrogen
Hydrogen escapes the water in the electrolysis as gas, and is collected in storage tanks.
Making hydrogen fuel
Discover how to turn water into green power

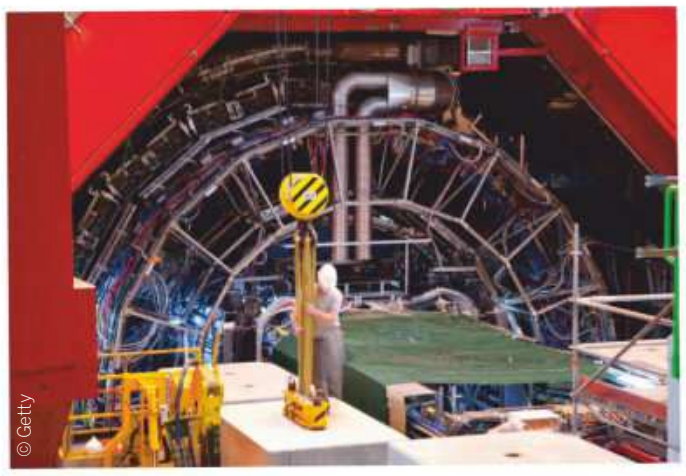
Green hydrogen production is gaining steam as one of the most viable clean fuel sources of the future

© Getty

# GREEN HYDROGEN REVOLUTION

Scientists are continuously looking for alternative fuel sources to decarbonise the Earth. As the climate crisis grows ever more prevalent, the need to find fossil fuel alternatives has never been greater. Green hydrogen is a renewable fuel resource that will be making waves in 2021. This type of fuel can be created by breaking off hydrogen atoms that are bound to oxygen atoms in water molecules using electricity supplied by other renewable energy sources, such as solar or wind power. The harvested hydrogen can be used as a fuel source for energy production and vehicles without creating damaging pollutants or carbon dioxide.

The production of hydrogen fuel is gaining momentum in countries around the world. For example, in Glasgow, Scotland, there are plans to begin construction of a 51-acre commercial hydrogen-production hub next year. It's estimated that the plant will initially produce 800,000 kilograms of hydrogen each year. Other countries such as Australia, the US and China are also exploring the potential of hydrogen power to produce zero-emission fuels. Germany has recently dedicated €9 million (£8 million) to green hydrogen production with the aim of becoming carbon neutral by 2050.



© Getty

On its second run between 2015 and 2018 the LHC achieved 16 million billion proton-proton collisions

## LARGE HADRON COLLIDER WAKES UP

**After a two-year snooze, the Large Hadron Collider (LHC) is due to reopen in May 2021. It's a 27-kilometre-long particle accelerator that uses rings of superconducting magnets to collide particles to better understand their physical properties and how they interact with one another. But this giant magnet at times needs a cooling-off period.**

**The LHC powered down in late 2018 as part of the planned 'Long Shutdown 2'. The first shutdown occurred between 2013 and 2015 to make vital upgrades to the LHC, and this second closure was no different.**

**During its two-year hiatus the particle accelerator has undergone several updates: the rings that accelerate the subatomic particles before forcing them to smash together have been renewed and the particle speed, mass and charge detectors will be upgraded.**

# BROOD X HATCHES

Billions of cicadas are due to emerge from the ground next spring. Commonly referred to as the 17-year locust – despite not actually being locusts – cicadas are small, cricket-like insects that spend a long time beneath the ground before emerging into adulthood.

There are over 3,000 species of cicada around the world, but these can be split into two general categories: those that annually reproduce and those that do it periodically every 13 or 17 years. Scientists still aren't sure exactly as to why these insects enjoy the comfort of the underground for so long, but it's commonly believed that this elongated period is an evolutionary strategy to avoid matching predator population cycles and finding themselves being eaten before they've had a chance to make the next generation.

Each female can produce hundreds of eggs before she dies, which over time has resulted in broods of billions digging their way out from the soil every 17 years or so. 2021 is the next big breakout: across 15 states in America, 'Brood X' will emerge around mid-May to late June when the ground temperature reaches around 18 degrees Celsius.

## Cicada life cycle

These insects spend more than a decade growing in the ground

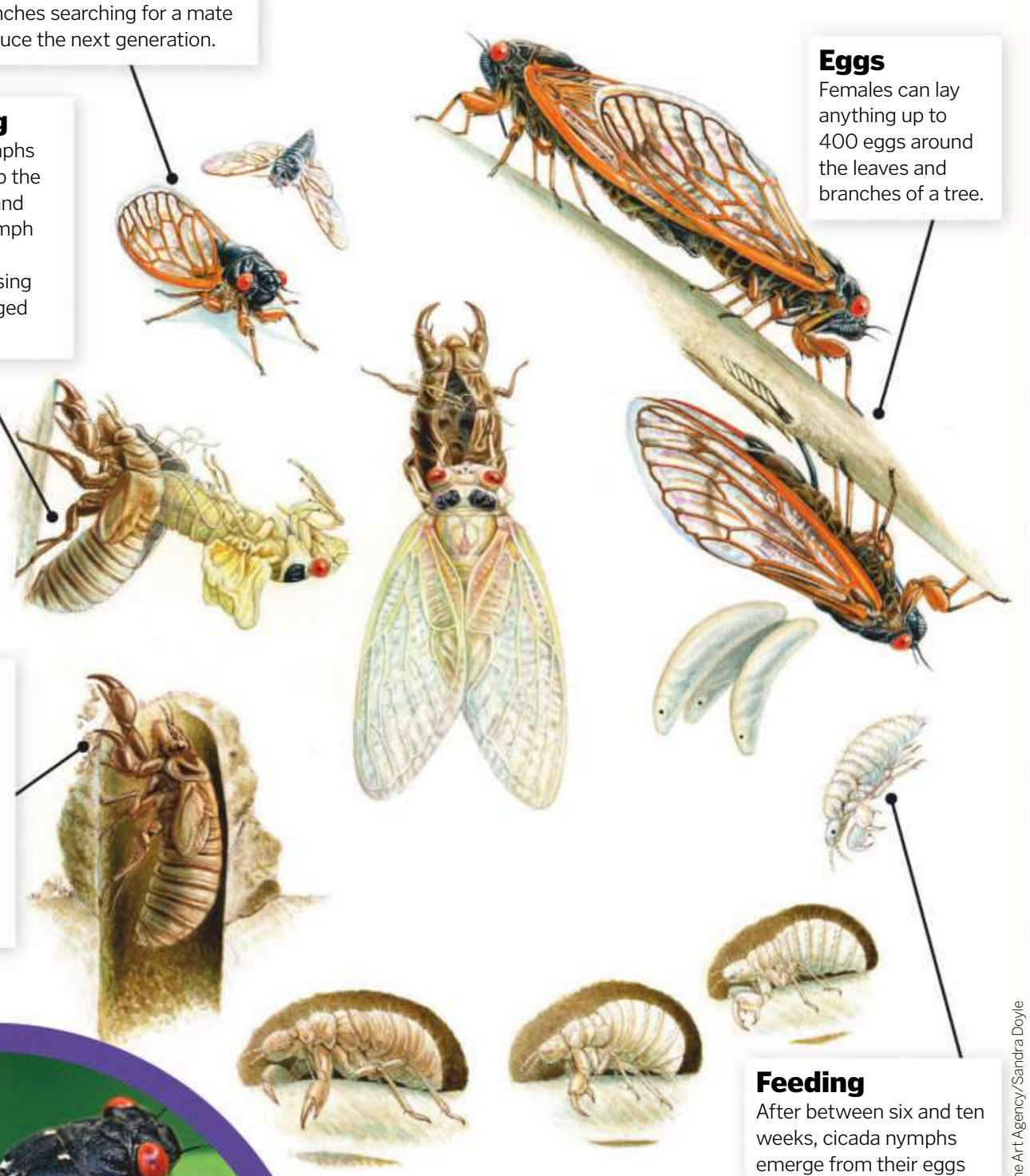
**Adulthood**
Cicadas typically spend their adult lives, which is only a few weeks, on branches searching for a mate to produce the next generation.

**Eggs**
Females can lay anything up to 400 eggs around the leaves and branches of a tree.

**Shedding**
Emerged nymphs will then climb the nearest tree and shed their nymph exoskeleton, metamorphosing into their winged adult form.

**Escaping the soil**
For periodical cicadas, it will take up to 17 years for the nymphs to finally dig channels to the surface.

**Feeding**
After between six and ten weeks, cicada nymphs emerge from their eggs and fall to the ground, where they burrow to the tree's roots to feed on the nutrients within.



© Illustration by The Art Agency/Sandra Doyle

© Getty

During the few weeks cicadas live above ground, they feast on vegetation as nymphs and moult into adults around five centimetres long

An annular eclipse over New Mexico, 20 May 2012

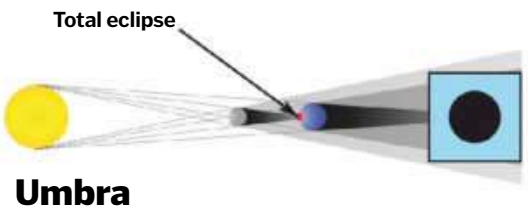
© Getty

## THE SUN WILL DISAPPEAR FOR A FEW SECONDS

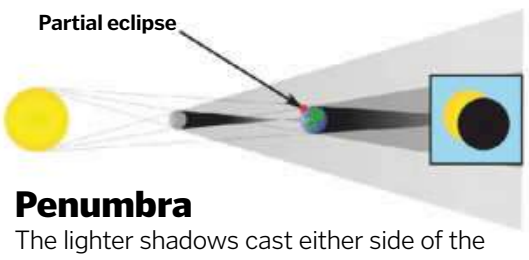
**On 10 June 2021, the Moon will cast a shadow over parts of Earth during an annular solar eclipse event. An annular eclipse only occurs during a new Moon when the Sun and Moon are aligned, and the Moon is at a lunar node – the point where the orbital planes of both Earth and the Moon align – and the Moon is at the furthest distance from Earth during its orbit, called its apogee, which can vary year on year. Countries in the uppermost reaches of the Northern Hemisphere such as northern Canada, Greenland and parts of Russia will witness the full extent of the eclipse, with Europe, America and Northern Asia seeing a partial eclipse.**

## Witnessing the ring of fire

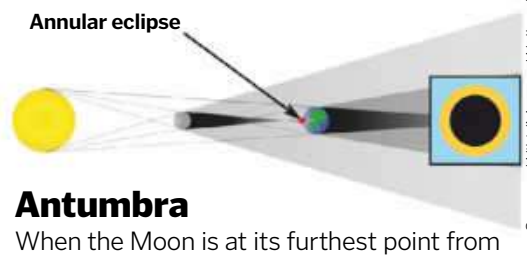
The type of solar eclipse you can see completely depends on which part of the Moon's shadow you're under




**Umbra**
This is the shadow cast by the Moon. When the Moon is closest to Earth during its elliptical orbit, the umbra will create a total solar eclipse.




**Penumbra**
The lighter shadows cast either side of the umbra reveal a partial solar eclipse.




**Antumbra**
When the Moon is at its furthest point from Earth, it appears at its smallest in the sky. The shadow cast, called the antumbra, allows the Sun's light to bleed around the Moon.

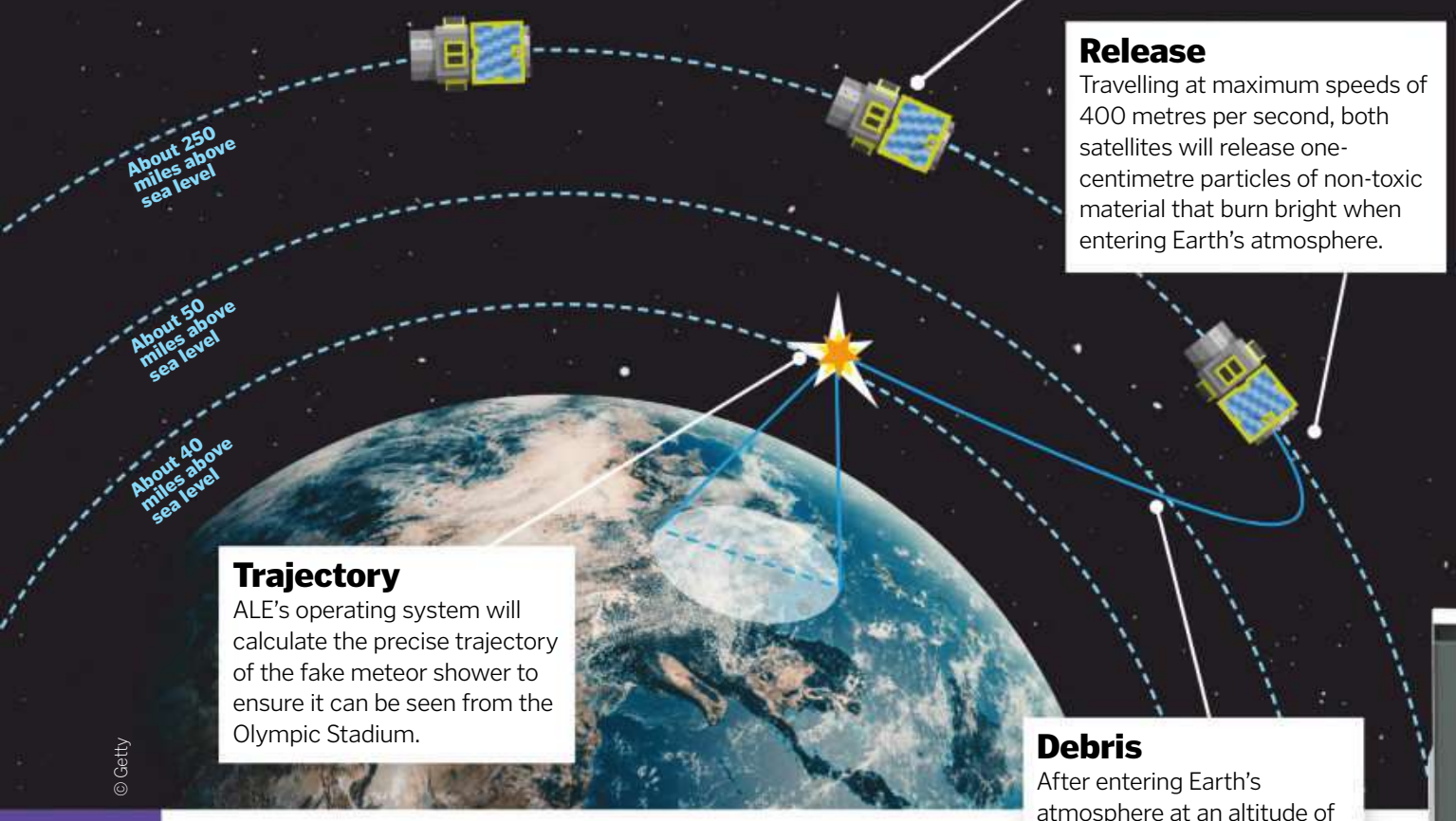
Source: Wiki/Messer Wolland

# HIGH-TECH OLYMPICS

## WHAT TECHNOLOGICAL ADVANCEMENTS CAN WE EXPECT FROM NEXT YEAR'S ATHLETIC GAMES?

## HUMAN-MADE METEOR SHOWERS

**As part of the opening ceremony of the 2021 Olympics, start-up company ALE will carry out a unique outer-space spectacular in the form of a human-made meteor shower. Rather than throwing rocks out of the window of a space rocket, orbiting microsatellites called ALE-1 and ALE-2 will release chemical pellets into the atmosphere. As they burn up on entry into the atmosphere, the pellets will emit a colour, creating the appearance of shooting stars from the ground.**




© Getty

### Satellites
Both ALE-1 and ALE-2 are equipped with sensors to detect altitude, so they know when and where to release meteor shower-producing particles.

### Release
Travelling at maximum speeds of 400 metres per second, both satellites will release one-centimetre particles of non-toxic material that burn bright when entering Earth's atmosphere.

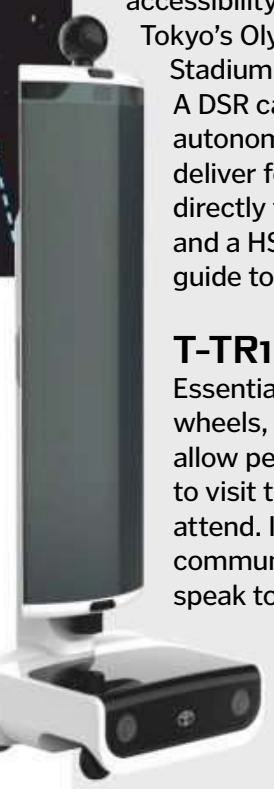
### Trajectory
ALE's operating system will calculate the precise trajectory of the fake meteor shower to ensure it can be seen from the Olympic Stadium.

### Debris
After entering Earth's atmosphere at an altitude of 50 miles, the pellet particles will vaporise before they can hit the ground.

## ROBOTIC ASSISTANCE

### FIELD SUPPORT ROBOT (FSR)
These autonomous robots will act as mechanical caddies during throwing events such as javelin and shot put. An FSR will be able to automatically follow staff to retrieve equipment and remove things from the field.

### SUPPORT ROBOTS
Both the Human Support (HSR) and Delivery Support Robot (DSR) will provide accessibility inside Tokyo's Olympic Stadium. A DSR can autonomously deliver food orders directly to spectators and a HSR will act as a guide to seat guests.



### T-TR1
Essentially a giant iPad on wheels, this next-gen robot will allow people physically unable to visit the event to virtually attend. It also has two-way communication so they can speak to virtual attendees.

### T-HR3
These humanoid robots could be placed inside and outside of Tokyo to mimic or reproduce movements from the mascot robots for those that can't attend the event. This can even include high-fiving and talking with athletes.

All boxout images © Toyota

## FLYING CARS

In 2017, Japanese car manufacturer Toyota invested hundreds of thousands of dollars in flying-car company Cartivator to create the SkyDrive: a personal flying car that operates not unlike a domestic drone, but on a larger scale to support the heavy payload of a human pilot. The intention was for the SkyDrive to be used to light the Olympic flame during the 2020 opening ceremony. There's hope the flying car will make an appearance at the rescheduled games, especially as in August 2020 SkyDrive completed a successful debut test flight.

© SkyDrive

Cartivator hopes to move SkyDrive flights out of the test ground soon

## SELF-DRIVING CARS GIVEN THE GREEN LIGHT

Back in 2016, the US Secretary of Transportation Anthony Foxx reportedly said that autonomous cars would be everywhere by 2021. Though that's not exactly the case yet, 2021 is shaping up to be the start of an era of self-driving functionality.

In recent years car manufacturers such as Ford, Toyota and Tesla have made enormous leaps in driving automation, such as the ability for a car to self-park, detect hazards on the road and ultimately drive itself. There are fleets of new cars with autonomous abilities set to be released throughout 2021, such as the Mercedes-Maybach S-Class, which is designed for 'chauffeur-driven journeys'. Although autonomous driving technology has been tried and tested to work, the law isn't currently in favour of self-driving cars in many countries. 2021 could see that change.

For example, in Japan, Honda has been granted permission to mass-produce next-generation cars with 100 per cent autonomous capabilities, with hopes to be on the roads by March next year. Also, the UK government is reportedly considering legalising automated driving at 70 miles per hour in the slow lanes of motorways in 2021.

# NEXT-GEN RESEARCH SHIP WILL SET SAIL

**It's been one of the most talked-about research vessels in recent years. This research superyacht, REV Ocean, could be ready to set sail on expeditions around the world by June. Announced back in 2017, REV Ocean was envisioned to be a state-of-the-art research vessel to explore the impact humans have on the oceans.**

**As a science vessel, research conducted on board the 182.9-metre-long behemoth will focus on three areas: plastic pollution, climate change and unsustainable fishing. To facilitate this vital research, the ship is packed with the latest research equipment, including an array of sensors, sonars, submarines and even a five-blade helicopter for overhead surveys.**

**This beast also has enough dry goods and freezer stores to support 90 people for 114 days at sea. With many strings to its bow, the REV Ocean can also operate as a chartered luxury ship for 28 guests and 54 crew for educational experiences and once-in-a-lifetime cruises.**

## On board the Rev Ocean

What will allow researchers to make the most of this science superyacht?

**Capacity**
Rev Ocean is capable of holding a crew of 54 with an additional 36 guests.

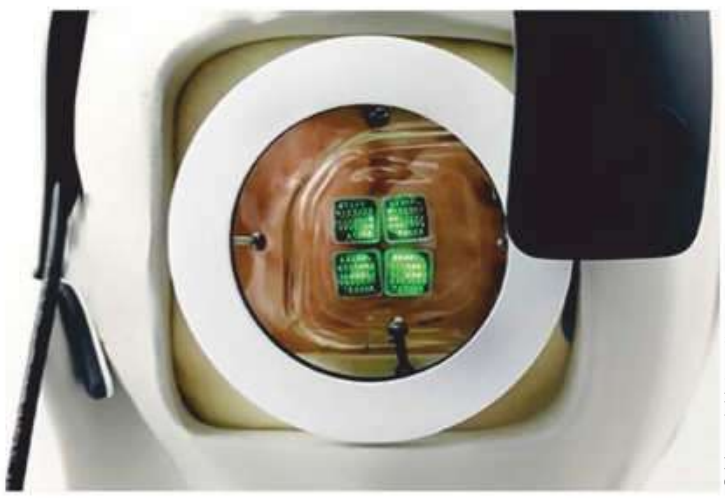
**Laboratories**
There are several laboratories on board the Rev, including an environmental research lab, geology lab and microbiology lab.

**Sonars**
Rev is equipped with echo sonars and sounders. These allow researchers to monitor fish species and map the sea floor.

# SEEING THROUGH BIONIC EYES

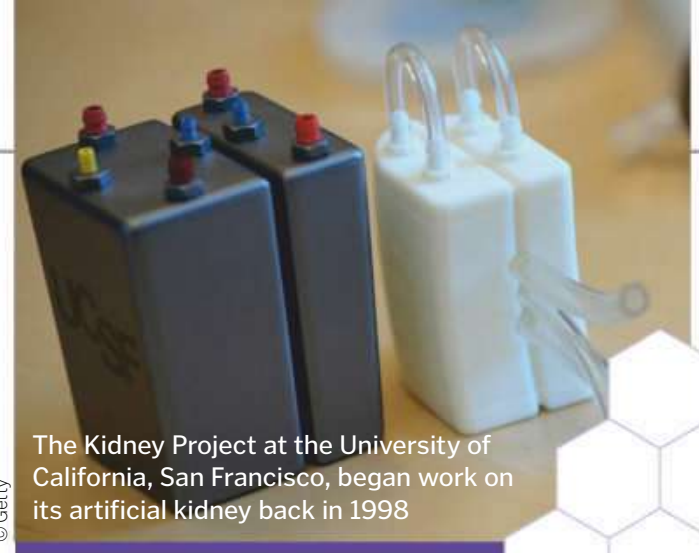
Monash University in Melbourne, Australia, is paving the way in restoring human eyesight with this revolutionary device, which will enter human clinical trials in 2021. The cortical vision device, called Gennaris, is in part an electronic implant that sits on the surface of the brain and works in tandem with a camera headset to restore vision to blind patients. While wearing the headgear, the camera captures the scene and sends the images wirelessly to the implanted device. Gennaris converts that information into electrical pulses, delivered through hundreds of hair-thin microelectrodes, to stimulate the visual cortex of the brain, which over time learns to interpret those signals as images.

A single headset unit combines a camera and wireless transmitter



© Monash University

Microelectrodes implanted into the brain will transcribe information from the external camera



© Getty

The Kidney Project at the University of California, San Francisco, began work on its artificial kidney back in 1998

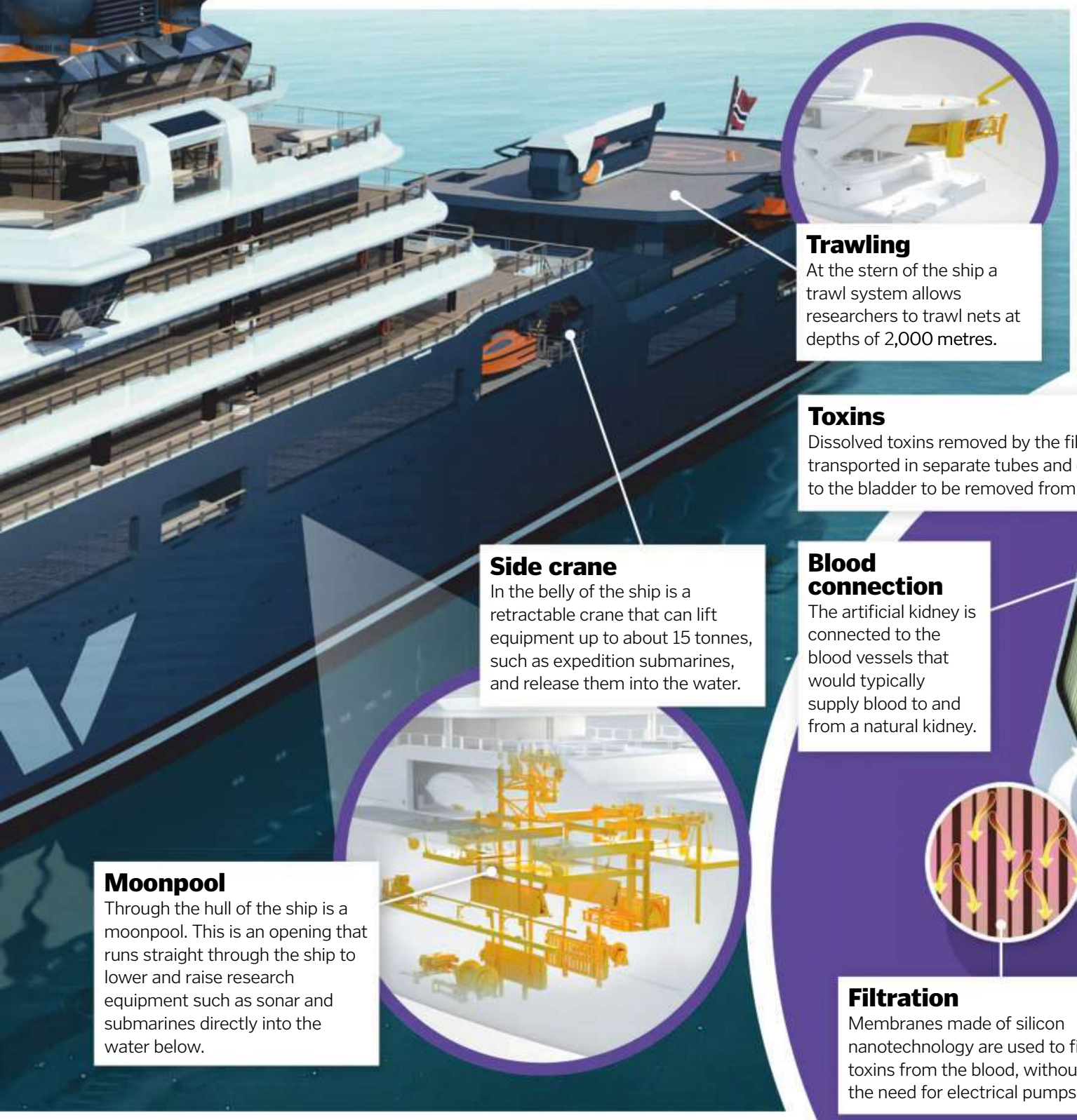
# ARTIFICIAL KIDNEY TRIALS END

**Kidneys remove toxic and waste substances from our blood, adding vital amino acids, sugars and hormones to keep us healthy. When a kidney is damaged or so diseased that it can no longer function by itself, a patient will typically undergo dialysis. Without a kidney transplant from a donor, dialysis is often a lifelong treatment.**

**However, innovations such as the iHemo by the Kidney Project could help alleviate the demand for human kidney transplants. Over the years there have been several scientific strides made in growing and even 3D-printing kidneys, though there has been limited success in creating a mechanical kidney substitute. However, the Kidney Project is expected to enter into the final stages of its clinical trials in late 2021.**

## Portable dialysis

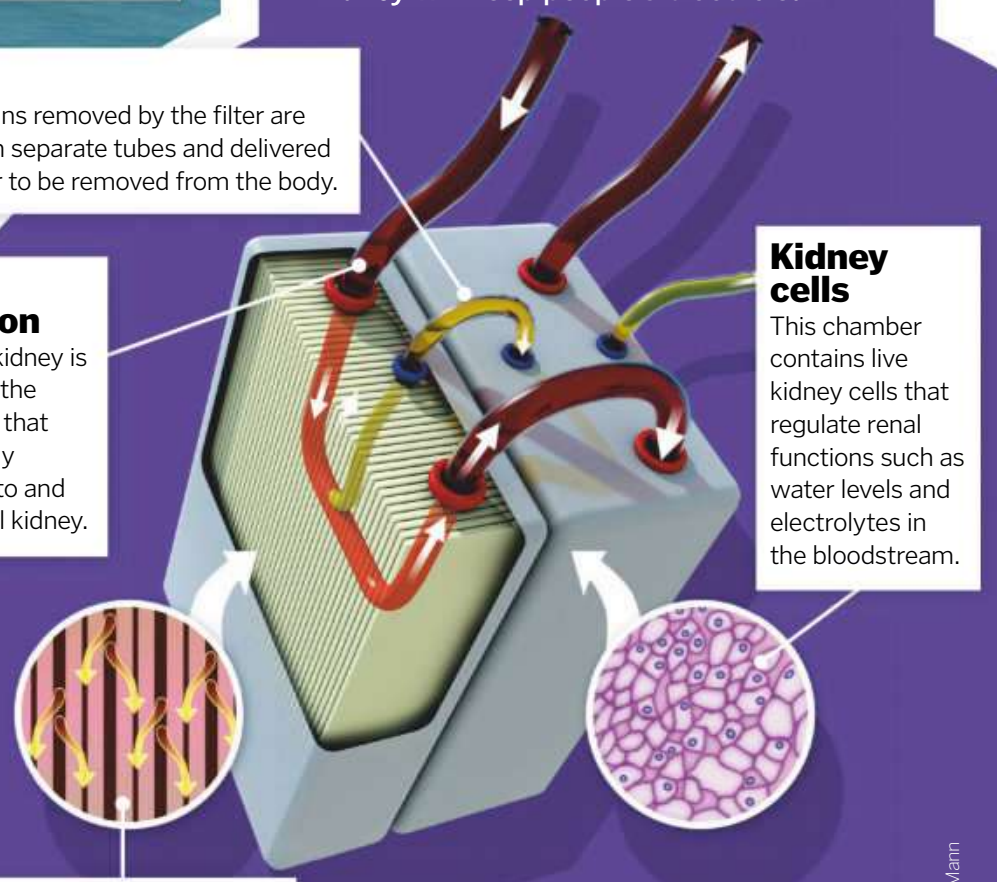
How the world's first implantable artificial kidney will keep people's blood clean



### Trawling
At the stern of the ship a trawl system allows researchers to trawl nets at depths of 2,000 metres.

### Side crane
In the belly of the ship is a retractable crane that can lift equipment up to about 15 tonnes, such as expedition submarines, and release them into the water.

### Moonpool
Through the hull of the ship is a moonpool. This is an opening that runs straight through the ship to lower and raise research equipment such as sonar and submarines directly into the water below.



### Toxins
Dissolved toxins removed by the filter are transported in separate tubes and delivered to the bladder to be removed from the body.

### Blood connection
The artificial kidney is connected to the blood vessels that would typically supply blood to and from a natural kidney.

### Kidney cells
This chamber contains live kidney cells that regulate renal functions such as water levels and electrolytes in the bloodstream.

### Filtration
Membranes made of silicon nanotechnology are used to filter toxins from the blood, without the need for electrical pumps.

**AR ZONE! SCAN HERE**

Illustration by © Adrian Mann

# NEW EYES IN THE SKY

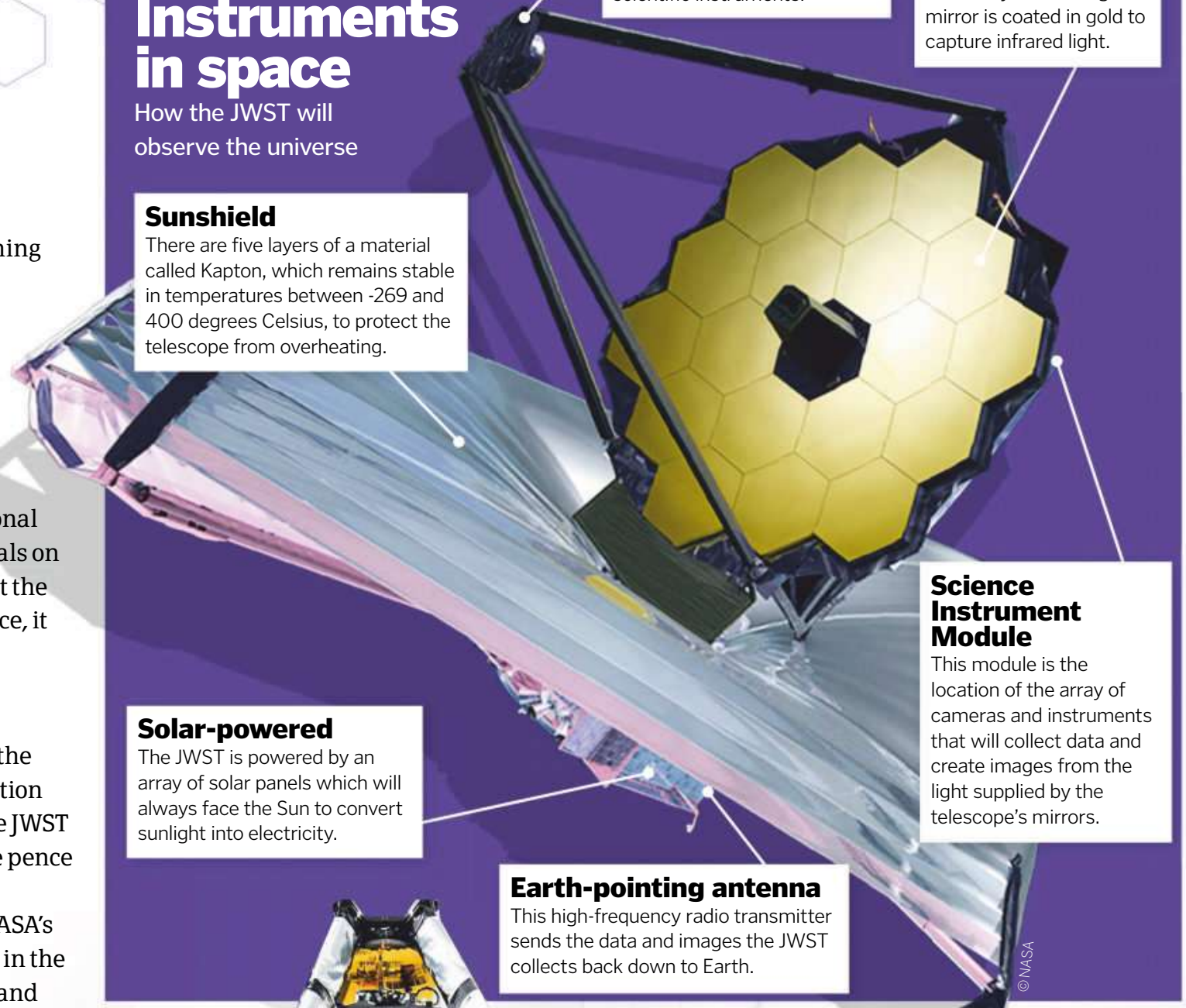
After many delays, the James Webb Space Telescope (JWST) might actually be launching soon. It's a large infrared telescope with a massive 6.5-metre primary mirror, much larger than the Hubble Space Telescope's 2.4-metre primary mirror. Its intended use will be to collect information, in the form of light and radiation, to uncover more about the history of the universe.

The mirror comprises 18 smaller hexagonal mirrors made from one of the lightest metals on Earth: beryllium. Although the JWST is not the first infrared telescope to journey into space, it will be capable of capturing images of the universe in unrivalled detail. Generally speaking, the bigger the mirror, the more infrared wavelengths can be collected by the telescope, which produces a higher resolution image. Thanks to its large mirror array, the JWST would be able to capture an image of a one pence piece from around 24 miles away.

It has been a long and bumpy road for NASA's next-gen telescope since its proposal back in the early 1990s. A wave of technical, financial and pandemic hurdles have kept the JWST on the ground. But now NASA has revealed that its target launch date is 31 October 2021.

## Instruments in space

How the JWST will observe the universe



**Secondary mirror**
The light gathered from the primary mirror is reflected from here into the telescope's scientific instruments.

**Primary mirror**
Each beryllium hexagonal mirror is coated in gold to capture infrared light.

**Sunshield**
There are five layers of a material called Kapton, which remains stable in temperatures between -269 and 400 degrees Celsius, to protect the telescope from overheating.

**Science Instrument Module**
This module is the location of the array of cameras and instruments that will collect data and create images from the light supplied by the telescope's mirrors.

**Solar-powered**
The JWST is powered by an array of solar panels which will always face the Sun to convert sunlight into electricity.

**Earth-pointing antenna**
This high-frequency radio transmitter sends the data and images the JWST collects back down to Earth.

© NASA

The James Webb Space Telescope will be NASA's successor to the famous Hubble Space Telescope

© NASA/Chris Gunn

Panasonic is developing VR glasses such as these with 5G compatibility

# 5G GIVES VIRTUAL REALITY AN UPGRADE

Virtual and augmented reality have infiltrated practically every industry across the globe, including **How It Works**! From engineering and medical training to out-of-this-world game design, VR technology is revolutionising our online experiences.

With the rollout of 5G technology around the world, 2021 could be the year the virtual world gets an upgrade. Current VR headsets depend on a connection to a WiFi network or PC to function, as 4G technology is not up to the task of supporting the demand they place on the bandwidth. However, 5G superfast wireless technology promises 100-times faster internet connections than 4G alternatives, and therefore headsets could be made mobile when supported with 5G smartphones.

5G also boasts a one-millisecond latency – the time required for data to travel between two points – as opposed to the 20 typically seen in 4G smartphones. This might not seem a lot when you're talking in milliseconds, but when it comes to VR it's vital, and can even affect a headset user – if internet latency is above 20 milliseconds, a VR headset user can begin to feel nauseous. There are several companies, such as Panasonic and Oppo, set to roll out a wave of new 5G-compatible headsets over the next 12 months.

# THE FIRST LAUNCH FOR ARTEMIS 1

**Another important launch will occur in November 2021 – part of NASA's long-awaited Artemis 1 mission. The unmanned spacecraft, Orion, will be sent beyond the Moon and back, controlled remotely from Earth. The flyby will extend 40,000 miles past the Moon, further than any human has travelled before. The entire journey will take around three weeks to complete, with the Artemis 1 mission and the Orion spacecraft ending its journey somewhere in the Pacific Ocean. This will be the first of three Artemis missions to achieve the ultimate goal of placing the next man and the first woman on the Moon by 2024.**

NASA's Orion spacecraft undergoing critical three-month-long testing earlier this year

# BATTLING COVID-19

**One of the most crucial scientific advancements likely to emerge in 2021 is mass COVID-19 vaccination. Since coronavirus began to spread across the world, countless research facilities and pharmaceutical companies around the world have been working to develop a vaccine at record speeds. However, as 2020 comes to a close, there appears to be a light at the end of the tunnel in the fight against COVID-19.**

**Reports of several vaccines boasting above 90 per cent effectiveness against the virus have surfaced, including a vaccine produced in a collaboration between pharmaceutical companies Pfizer and BioNtech. The vaccine was tested on 43,000 people and has shown no safety concerns. Although the global rollout timescale and distribution of these vaccines remains unclear and will differ for different countries, it's safe to say that 2021 could see worldwide vaccinations.**

© Getty

In less than a year, scientists have created a COVID-19 vaccine

# KEY DATES

## WHAT SCIENCE EVENTS SHOULD YOU KEEP IN YOUR CALENDAR?

### CES 2021

www.ces.tech

JANUARY 11-14

It's the tech event of the year, and one of the most attended around the world. However, this time the Consumer Electronics Show (CES) will have an all-digital makeover to showcase technological innovations and advancements of the future.

### British Science Week

www.britishscienceweek.org

MARCH 5-14

Celebrating all things science, technology and engineering across the whole of Britain, this ten-day event will be packed with activities, competitions and plenty of information to inspire the next generation of scientists.

### Bluedot Festival

www.discoverthebluedot.com

JULY 22-25

Held at the Jodrell Bank Observatory in the UK, this event combines live music, scientific talks, astronomy and much more to create a festival that's truly out of this world.

### British Science Festival

www.britishscienceassociation.org

SEPTEMBER 7-11

This free four-day event is Europe's longest-standing science festival and is packed full of workshops, talks and events covering an array of scientific disciplines.

### New Scientist Live

live.newscientist.com

OCTOBER 14-17

The long-awaited New Scientist Live 2021 will bring together some of the greatest minds around the world to speak about a range of scientific subjects and showcase ground-breaking innovations.

# THE DEEPEST HOLES IN THE WORLD

## How deep have we ventured into Earth towards the core?

Words by **Ailsa Harvey**

Usually, when humanity lacks knowledge, we feel the need to explore new territory. We can do this by travelling or finding new tools to uncover the answers. Some environments are easier to explore than others, regardless of distance. In fact, during the 1960s and 1970s we set foot on the Moon hundreds of thousands of miles away, before we'd even explored a few tens of miles beneath the Earth's crust.

We have become incredibly familiar with the Earth's surface, inhabiting the majority of it without that much insight into the geology below. However, what lies beneath us is a question scientists have pondered and theorised about for centuries. Without seeing it, modern technology has allowed us to determine the structure of the Earth by studying seismic waves and how they travel through its layers. Even interpreting the results of this relatively accurate method doesn't display the full details of what is down there, however. This was one of the reasons we began drilling.

Many of our planet's deepest holes were created by humans for the purpose of extracting minerals or conducting science experiments. Some are carved by nature and others have been bored into the ground purely out of curiosity. Although we've set ourselves the goal, humans have never reached Earth's mantle, which takes up 84 per cent of Earth's volume.

Employing a team to hack into the ground might seem like a simpler way to learn about the insides of our planet than analysing data from waves. But by digging we have been able to confirm if our theories were accurate. This is a selection of the deepest locations discovered on Earth, each with a history of providing us with valuable materials or crucial information about our planet.

© Getty

# WORLD'S DEEPEST

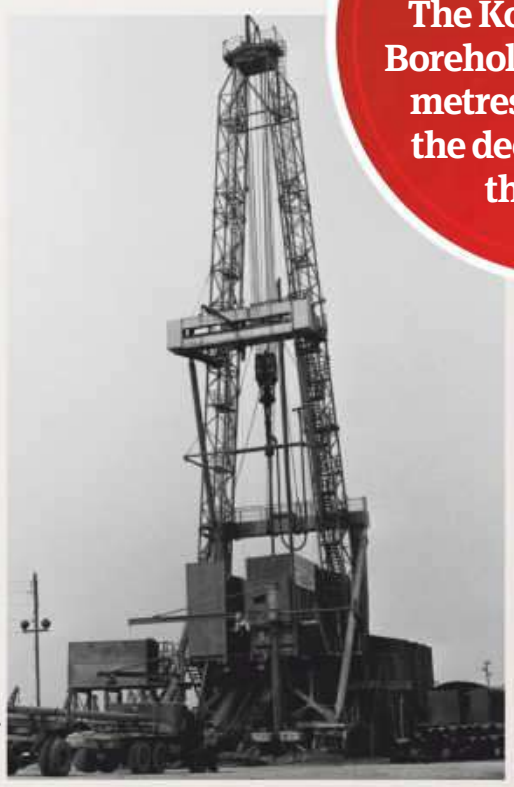
**Kola Superdeep Borehole** RUSSIA
**Depth** 12,262 METRES

The Space Race was a well-documented Cold War competition between the US and Soviet Union to be the first to send humans into space, exploring further than we had ever been. But this isn't where their racing stopped. While these nations were looking to the stars, they also challenged each other in attempts to be the first to dig as far into the Earth as possible. Their main aim? To reach the mantle.

Neither would get this far, but what the Soviets did achieve was producing the deepest hole in the world: the Kola Superdeep Borehole. This thin, tunnelling path divides into multiple routes, with the deepest reaching over 12,000 metres down. That's around one-third of the distance through the continental crust.

The attempt also provided access to more geological data of Earth than a dig had ever been capable of. They discovered that the granite rock continued for the entire depth covered, while before this scientists anticipated a change to basalt at around 3.7 miles. Another big discovery came when they retrieved fossils that had survived in extreme conditions for over 2 billion years.

**LONG DIVE**
**The Kola Superdeep Borehole reaches 1,000 metres further than the deepest point in the oceans**



© Getty

The Kola Superdeep Borehole drilling installation, in 1986

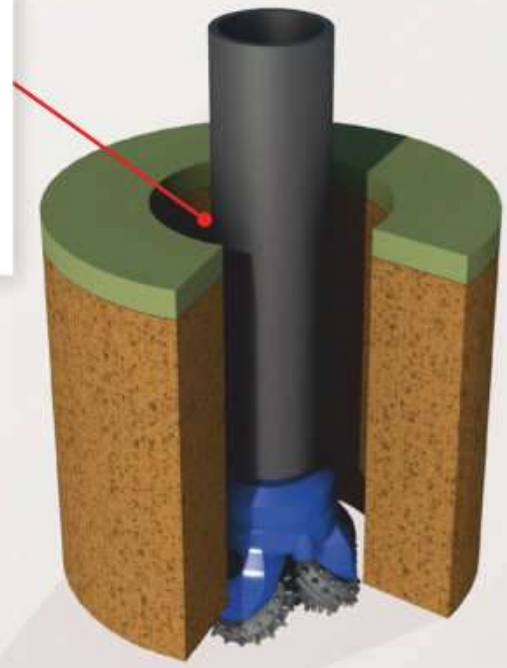
Source: Wiki/Rakot13

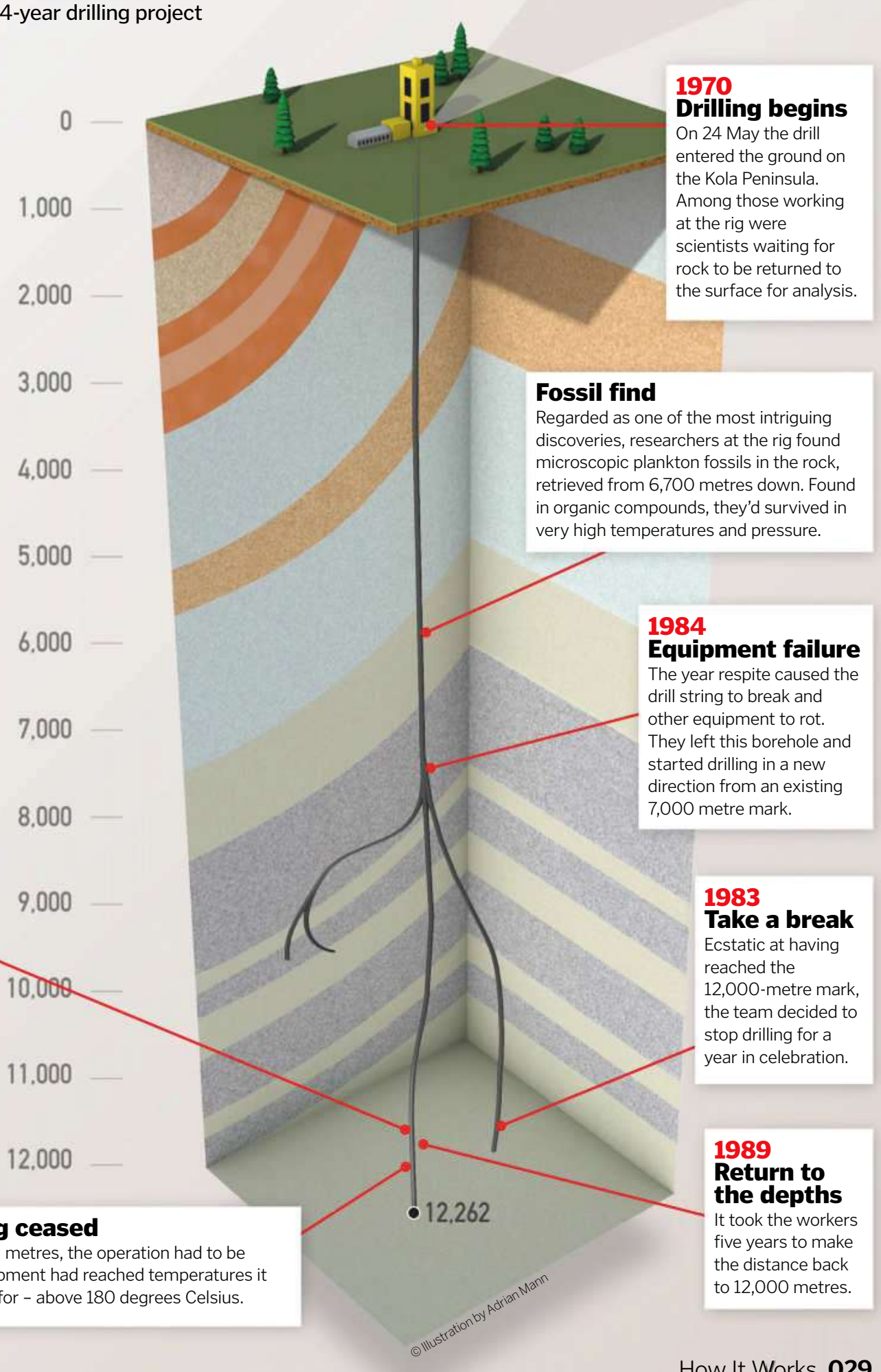
The Kola Superdeep Borehole's entrance has been welded shut, but often attracts visitors

## 12,000 metres down

How the Soviet Union embarked on this 24-year drilling project

**Narrow entrance**
Only 23 centimetres in diameter, the drill left behind a narrow yet extensive hole.






**1970 Drilling begins**
On 24 May the drill entered the ground on the Kola Peninsula. Among those working at the rig were scientists waiting for rock to be returned to the surface for analysis.

**Fossil find**
Regarded as one of the most intriguing discoveries, researchers at the rig found microscopic plankton fossils in the rock, retrieved from 6,700 metres down. Found in organic compounds, they'd survived in very high temperatures and pressure.

**1984 Equipment failure**
The year respite caused the drill string to break and other equipment to rot. They left this borehole and started drilling in a new direction from an existing 7,000 metre mark.

**1983 Take a break**
Ecstatic at having reached the 12,000-metre mark, the team decided to stop drilling for a year in celebration.

**1989 Return to the depths**
It took the workers five years to make the distance back to 12,000 metres.

**1992 Retreat**
The operation was officially declared over after it was decided that it was too difficult to continue drilling in the softer, hot rock. The longest branch was named SG-3.

**1989 Drilling ceased**
Gaining a final 262 metres, the operation had to be stopped. The equipment had reached temperatures it was not prepared for – above 180 degrees Celsius.

© Illustration by Adrian Mann

**AR ZONE! SCAN HERE**

# DIGGING FOR DIAMONDS

**Mir mine** EASTERN SIBERIA
**Depth** 525 METRES

**Used as an open-pit diamond mine between 1957 and 2001, closing for good in 2004, Mir mine provided 10,000,000 carats (2,000 kilograms) of diamond annually. The estimated value to have been extracted from this mighty hole is over £13 billion ($17.3 billion). When it was being dug, the extreme climate slowed progress, with the ground being frozen solid for seven months of the year. During the winter season, those working on this mine had to thaw the ground with jet engines before using dynamite to move the earth.**

**Now that space has been cleared, how can it be put to use as its diamond abundance continues to decrease? There are potential future plans to build homes in this pit, converting it into a city of the future. The domed city of Mir is a design to convert the hole into a luxury self-contained city. If this goes ahead the 1,100-metre opening will be covered in a huge glass dome, have apartments lining the mine's walls and house a central green space.**

## NO-FLY ZONE

**Helicopters are banned from flying over Mir mine due to rumours that it can suck in aircraft**

© Getty

The mining town of Mirny is home to 40,000 people

The IceCube Observatory was completed in December 2010

© Science Photo Library

## DEEP SPACE

**IceCube has detected 28 neutrinos that originated outside of the Solar System**

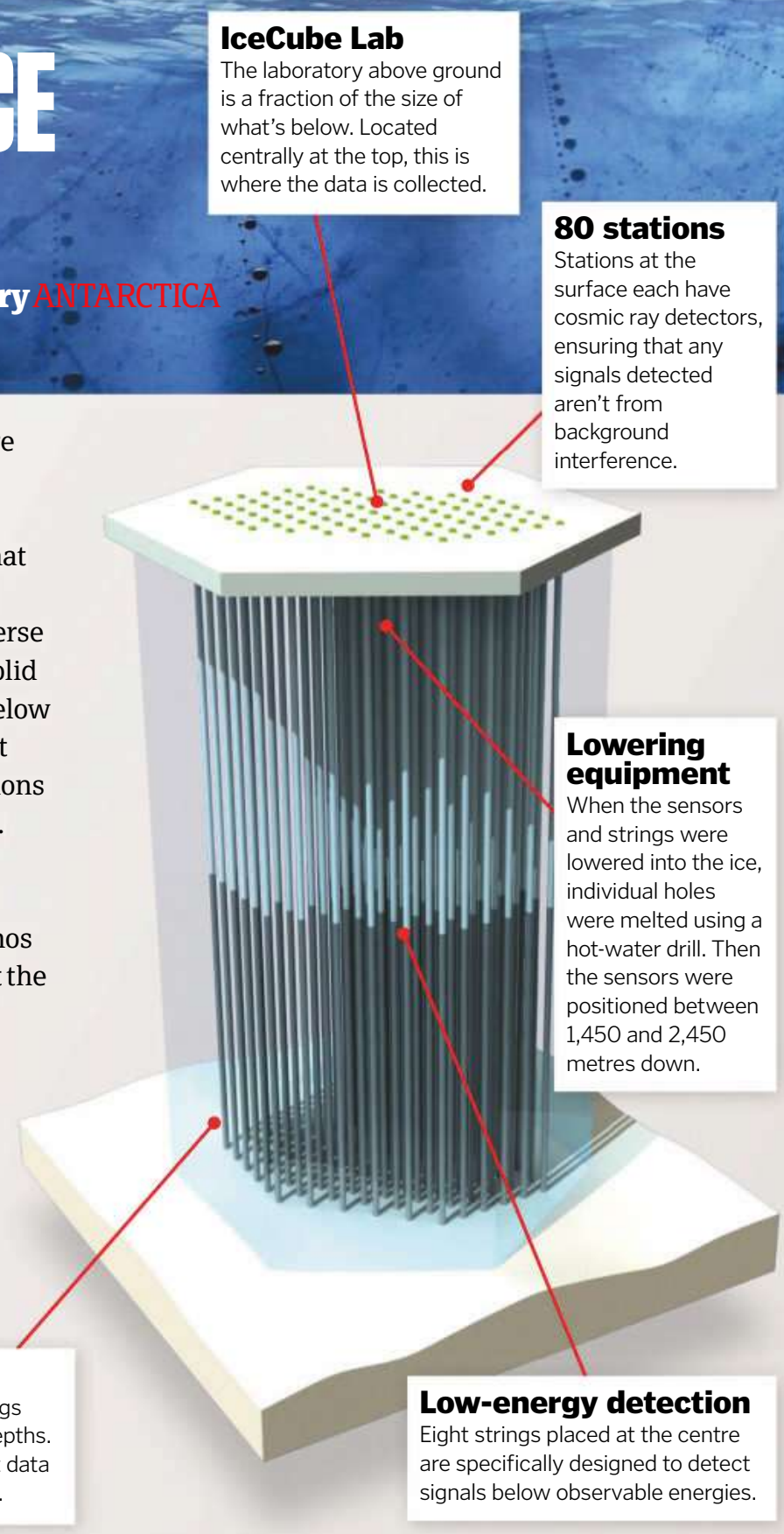
# SUBSURFACE SCIENCE

**IceCube Neutrino Observatory** ANTARCTICA
**Depth** 2,820 METRES

Sometimes large-scale operations are needed in order to obtain detailed information about something tiny. Neutrinos are chargeless particles that have no mass, and despite being the most abundant particles in the universe are close to impossible to observe. Solid ice was removed down to 1.5 miles below Antarctica's surface in order to detect these particles, which are many billions of times smaller than a grain of sand. Most of the work carried out in the IceCube Neutrino Observatory takes place underground. Here the neutrinos can be detected and studied without the interference of cosmic rays or other background radiation.

## Detecting neutrinos

How this underground observatory operates deep beneath the freezing Antarctic surface



**IceCube Lab**
The laboratory above ground is a fraction of the size of what's below. Located centrally at the top, this is where the data is collected.

**80 stations**
Stations at the surface each have cosmic ray detectors, ensuring that any signals detected aren't from background interference.

**Lowering equipment**
When the sensors and strings were lowered into the ice, individual holes were melted using a hot-water drill. Then the sensors were positioned between 1,450 and 2,450 metres down.

**86 strings**
Stretching the length of the hole, these strings hold spherical optical sensors at different depths. With 60 sensors on each string, they collect data from 5,160 locations within the observatory.

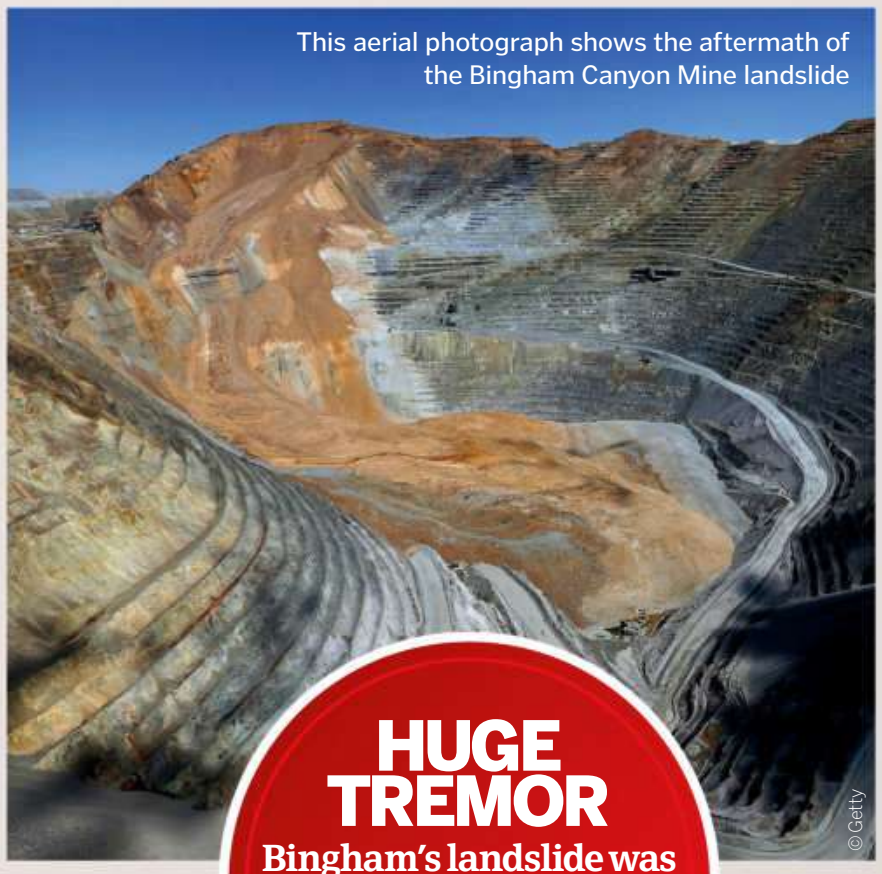
**Low-energy detection**
Eight strings placed at the centre are specifically designed to detect signals below observable energies.

# COLLAPSE OF THE RICHEST HOLE

**Bingham Canyon Mine** UTAH **Depth** 1,210 METRES

18 miles away from Salt Lake City, Utah, the ground gives way to Bingham Canyon Mine. Created in order to extract valuable copper, gold, silver and molybdenum for producing steel alloys, the mine became known as 'the richest hole on Earth', as it produced billions of dollars worth of materials.

Although enormous cavities appear impressive, removing this volume of land can make the surrounding earth much less stable. In April 2013 the hole caused the largest non-volcanic landslide in North American history. Around 70 million cubic metres of land cascaded into the centre. Fortunately, while the scale of the landslide was shocking, the event itself was foreseen. Mining operators had installed a radar system that had detected the change in stability, and were able to evacuate the death trap in time.



This aerial photograph shows the aftermath of the Bingham Canyon Mine landslide

© Getty

**HUGE TREMOR**

**Bingham's landslide was big enough to be detected by seismic networks designed for earthquakes**

# COPPER CHASM

**Chuquicamata mine** CHILE **Depth** 1,100 METRES

**Not only does this mine boast impressive depth, it's also one of the largest open-pit copper mines. With 140,000 tonnes of ore being mined and treated each day, Chuquicamata has been the source of a quarter of Chile's copper for over a century. Copper had been mined here for years, but in 1911 this large-scale modern mine was created. It has only increased in depth since. Next to this gaping pit in the Atacama Desert is a small, abandoned mining town where the early miners who created this hole used to live with their families. Now it's deemed too dangerous due to dust in the air.**

**The mine is currently at its maximum depth, being too large, old and dangerous to continue growing as an open pit. Instead a project is underway to convert it into the world's largest underground mine. Inside, on the layered paths gradually leading down the walls, trucks as tall as two-storey houses work to haul the copper from the deepest points.**

**SPOOKY FIND**

**The mummy of a miner from 550 AD was discovered in the ground at Chuquicamata**

Chuquicamata mine is over 1.8 miles wide

© Getty

# THE OCEAN'S HOLLOWS

**Dragon Hole**
SOUTH CHINA SEA
**Depth** 300 METRES

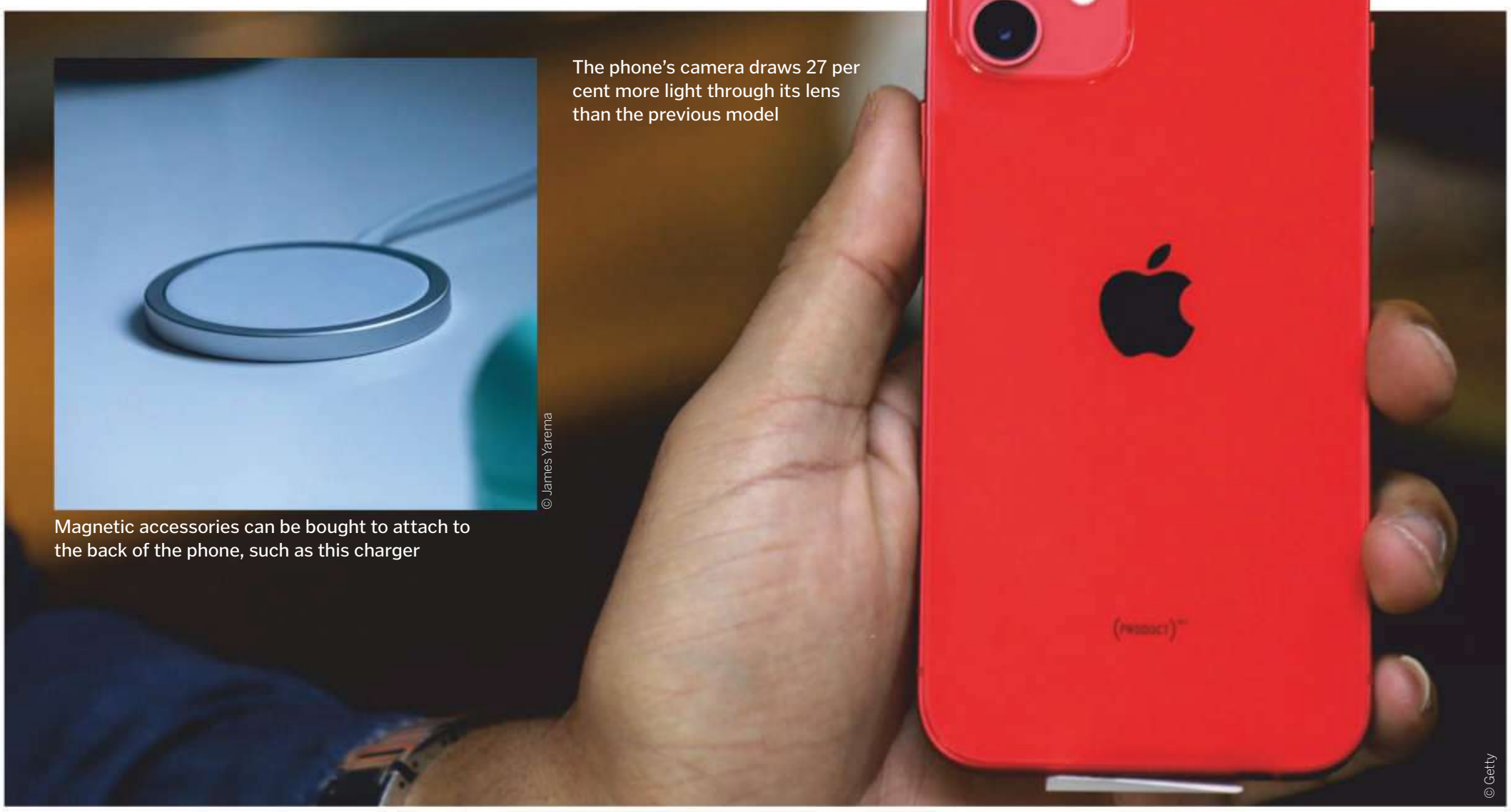
The deepest known holes were made by humans, but nature itself is capable of producing its own mighty sinkholes. Of those discovered, the one that reaches farthest underground can be found in the Paracel Islands, 250 miles away from central Vietnam. Also called the Sansha Yongle Blue Hole, the blue hole is home to 20 fish species in its top half, yet is lifeless past the 200-metre mark. This is because there is such little oxygen at its base. Blue holes were created during the Ice Age, when glacial runoff dissolved the limestone ground. This produced giant holes in the Earth, and when the glaciers finally melted through, the holes were filled with water.

**ROBOT DIVER**

**The deepest blue hole was discovered in 2015, and an underwater robot was sent in to investigate it**

Blue holes get their name from the contrasting dark shade of blue, signifying much deeper water

© Getty





Magnetic accessories can be bought to attach to the back of the phone, such as this charger

© James Yarema

The phone's camera draws 27 per cent more light through its lens than the previous model

© Getty

# Inside a 5G smartphone

## **How It Works** deconstructs Apple's iPhone 12

One of the main reasons smartphones have become such a necessity is their ability to keep us connected with increasing bandwidth and accessibility. Apple has now entered the world of 5G technology with its latest release, the iPhone 12. It's the first 5G-compatible iPhone, taking advantage of 5G networks as they expand across the globe.

Alongside this wireless technology update, the phone has a tougher exterior, higher quality camera and a thinner design. One of its standout external features is the multiple cameras at the back. Like the iPhone 11, the 12 comes with two lenses – standard-wide and ultra-wide – with a third on the Pro model, including a tele module. This allows clear photographs to be taken from a greater distance and with a longer focal length.

In keeping with the trend of speed and ease of access, a new MagSafe feature has been added to the back of the iPhone. This magnetic function allows accessories to be attached wirelessly, while a chip inside works out which tool has been added in order to launch it.

The first accessories released are a limited selection, including a charger and secure wallet holder. However, just as the 5G should add to the value in time, this feature could result in a surge of add-ons being produced by third-party manufacturers, from battery extensions to games console controllers.

### Downsizing

**In the iPhone 12 series there is a variety of size options, including the iPhone 12 Max and the iPhone 12 Mini. The Mini is less than 14 centimetres long, making it the smallest phone that Apple has released in recent years. To please those who miss being able to grasp their phone firmly in their palm, this model is only marginally larger than the iPhone 4. Showing how compact a new generation of devices can be, it has become the smallest 5G phone released.**

**The only features that have reduced, along with the size, are the battery life and the price. By proving that the newest smartphone tech doesn't need a bigger display to perform its functions, the iPhone 12 is creating more room for personal preference when it comes to design.**

For size comparison (left to right): the iPhone 4, SE 2020, 12 Mini, 12 and 12 Pro Max

© Ifixit

## 1 Rectangular design

The phone screen is nearly 15 centimetres long, making it the same size as the iPhone 11. It's rectangular, rather than having the curved edges of previous models.

## 2 Camera shields

The iPhone 12 Pro's extra camera module is a LiDAR sensor. This measures the distance of objects in the frame for better depth perception in photos.

## 3 SIM-card reader

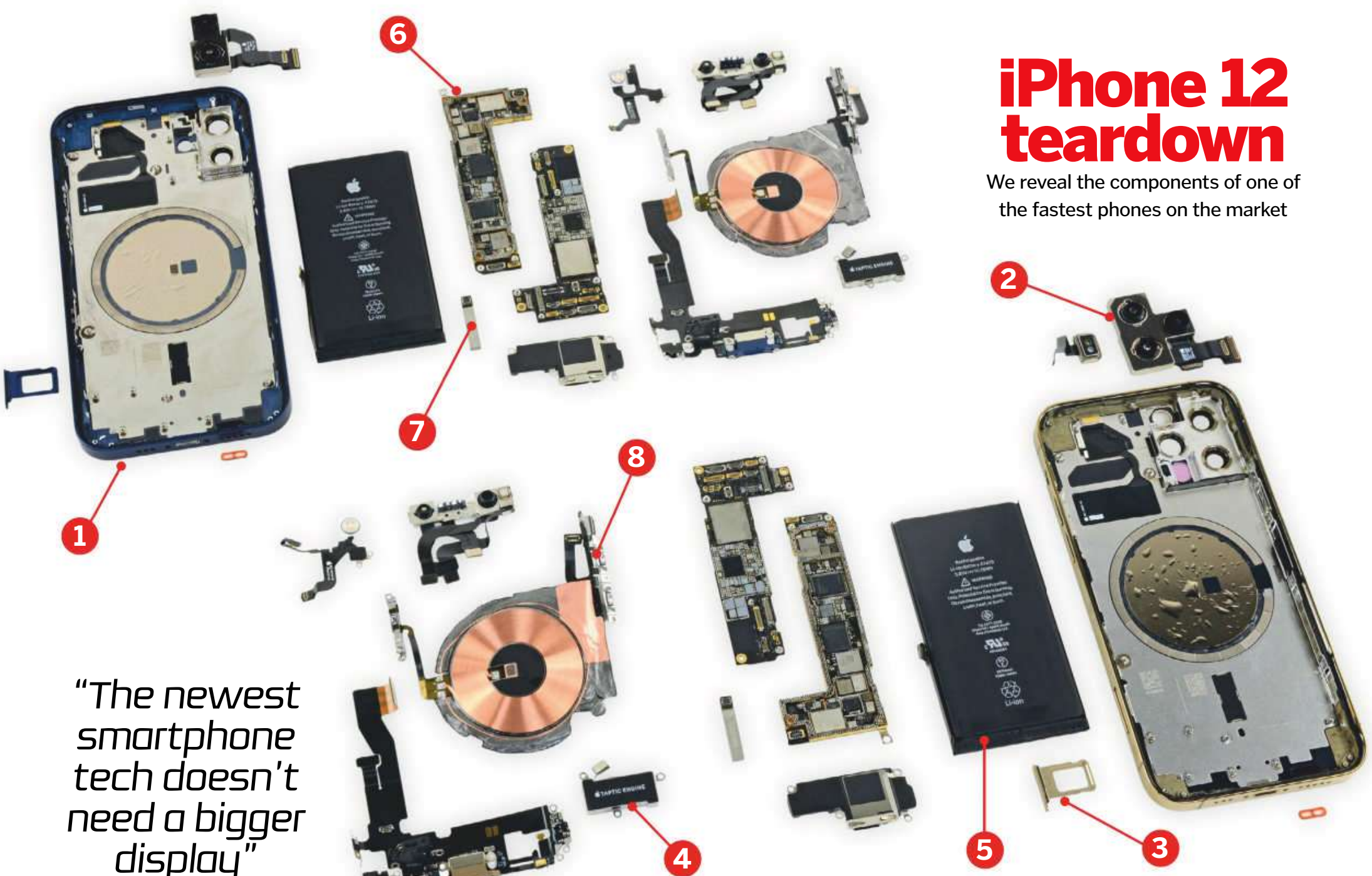
The SIM card tray is found at the side of the phone, near the volume buttons. It has swapped sides with other features to make room for 5G chips.

## 4 Taptic engine

Providing haptic feedback, this engine creates vibrations when receiving a message or confirming an Apple payment to alert the user.

# iPhone 12 teardown

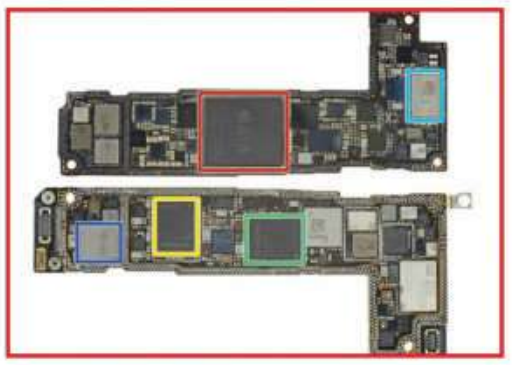
We reveal the components of one of the fastest phones on the market




*"The newest smartphone tech doesn't need a bigger display"*

## 5 Battery

Despite having a battery capacity of 10.78Wh, down from the iPhone 11's 11.91Wh, its efficiency means the battery should have more life on a full charge.



## 6 Logic board

The main circuit board has changed shape from a standard rectangle to an 'L' shape. This could be to control heat and utilise space within the phone.

## 7 5G mmWave antenna

To increase the bandwidth for 5G, these antenna modules run the length of the phone to allow for much better data connectivity speeds.

## 8 Magnet array

To allow for wireless charging, the central coil can carry 15 watts of power. This makes it twice as powerful as the wireless charging function on previous iPhones.

Images on page © iFixit

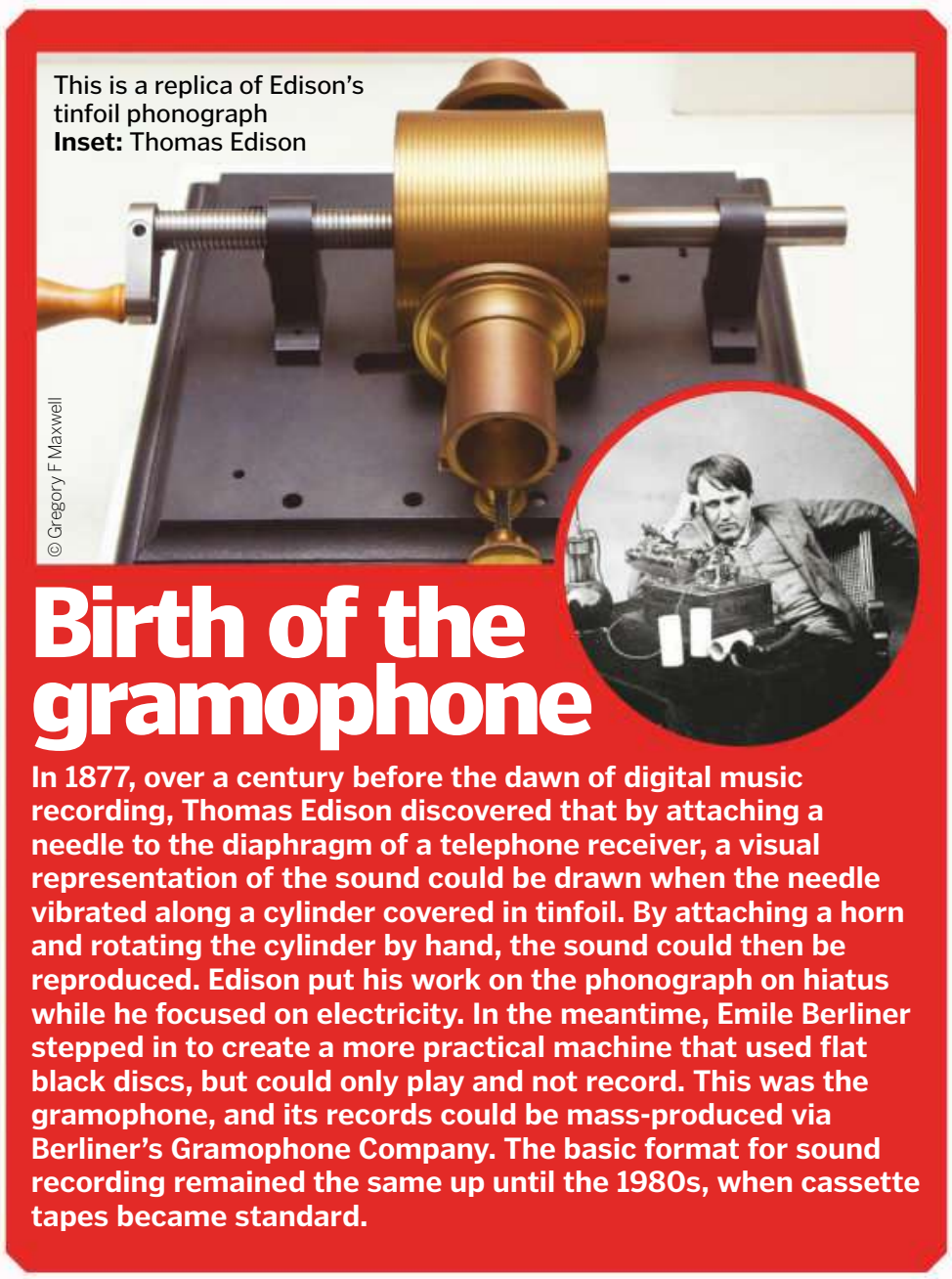
# Record players

## How sound is recorded and replayed from vinyl

Vinyl records are the audio storage media of yesteryear – though they are having a re-emergence in popularity. You can think of them as MP3 players that simply store sound using a different system: older hard-disk drives use magnetism to store this information, reading and writing using an arm that sweeps back and forth across spinning magnetic plates. Flash-memory music players like iPods, meanwhile, make use of transistor technology to store digital music, while compact discs have tiny pits pressed into the silver layer by a laser, which can be read by a CD player.

Records work in a very similar – if more tangible – way to the latest playback devices, though the same principles behind 19th-century phonographs can be seen at work in modern turntables. The tiny grooves in the record vibrate a crystal in the stylus, or needle, at the end of the arm as it moves across the record's surface. The resulting microscopic jolts move a metal bar that squeezes a piezoelectric crystal, generating an electric signal. The signal is fed to the amplifier that interprets it, then sends it out to the speakers which replicate the original sound.

Today's records are made of vinyl, pressed from a metal 'mother' that is cut using highly specialised machines. But even though the recording is of a much higher quality, you can still spin the turntable by hand to hear the record play without any intervention from modern technology.



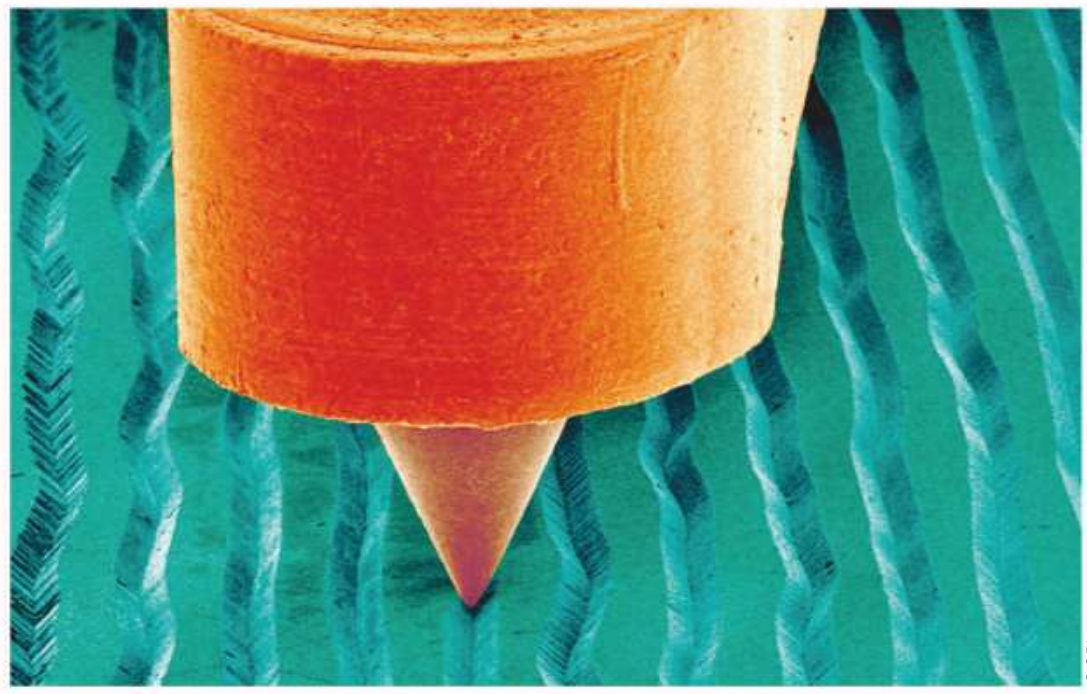
This is a replica of Edison's tinfoil phonograph
**Inset:** Thomas Edison

© Gregory F Maxwell

## Birth of the gramophone

**In 1877, over a century before the dawn of digital music recording, Thomas Edison discovered that by attaching a needle to the diaphragm of a telephone receiver, a visual representation of the sound could be drawn when the needle vibrated along a cylinder covered in tinfoil. By attaching a horn and rotating the cylinder by hand, the sound could then be reproduced. Edison put his work on the phonograph on hiatus while he focused on electricity. In the meantime, Emile Berliner stepped in to create a more practical machine that used flat black discs, but could only play and not record. This was the gramophone, and its records could be mass-produced via Berliner's Gramophone Company. The basic format for sound recording remained the same up until the 1980s, when cassette tapes became standard.**

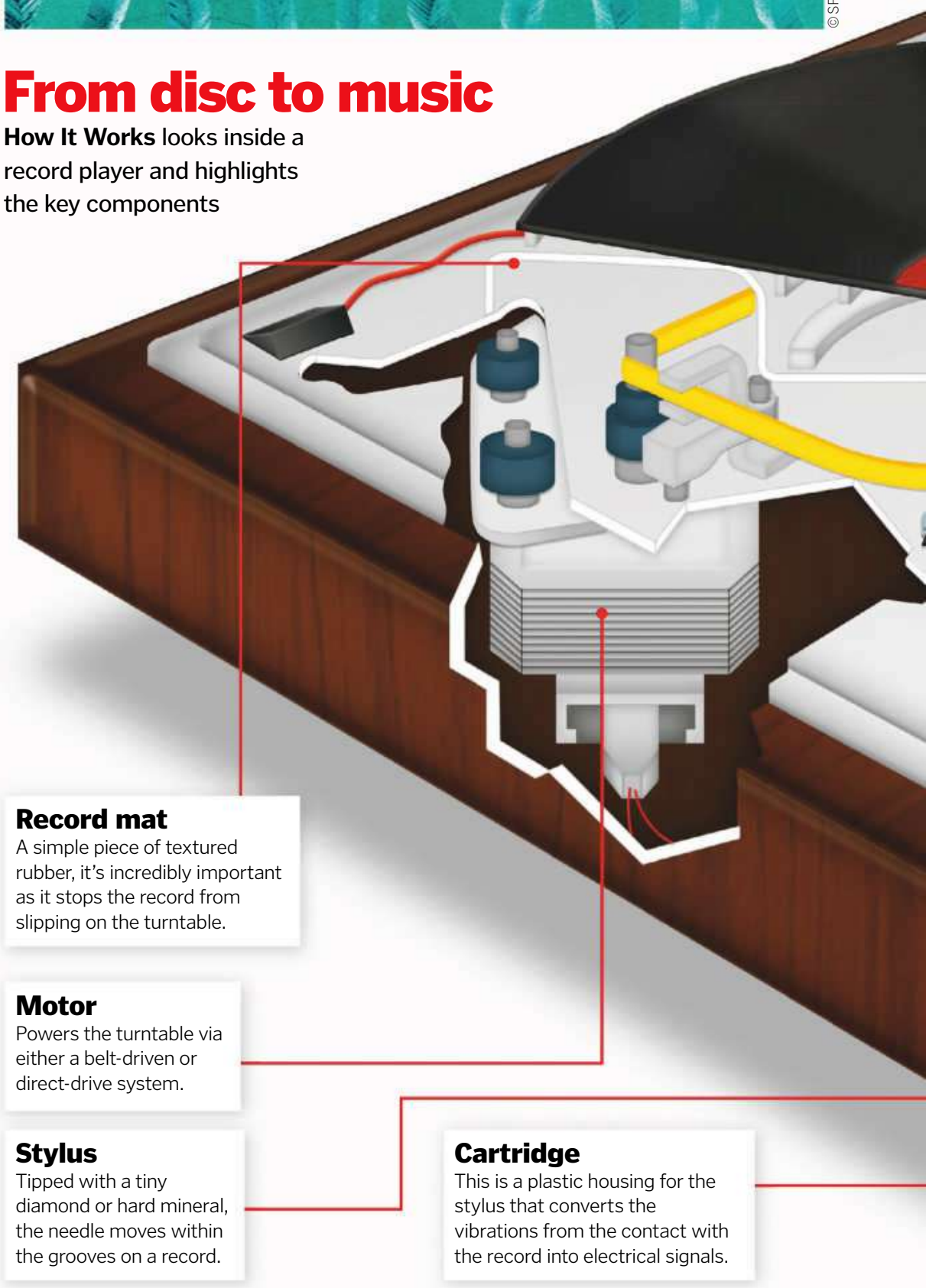
A shot taken by a scanning electron microscope of a stylus running along a groove in a record



©SPL

## From disc to music

**How It Works** looks inside a record player and highlights the key components



**Record mat**
A simple piece of textured rubber, it's incredibly important as it stops the record from slipping on the turntable.

**Motor**
Powers the turntable via either a belt-driven or direct-drive system.

**Stylus**
Tipped with a tiny diamond or hard mineral, the needle moves within the grooves on a record.

**Cartridge**
This is a plastic housing for the stylus that converts the vibrations from the contact with the record into electrical signals.

How we consume music has changed radically over the last century

**Record**
The record is pressed from a 'biscuit' of vinyl, though they were first made of shellac, the resin from the scaly lac bug.

**Tonearm**
This mechanical arm, also known as the pickup, glides across the record with the stylus and delivers the electrical signals into the amplifier.

**Servo**
This highly engineered box of tricks controls stylus pressure and helps prevent the arm from skating across the vinyl disc.

**Turntable**
Modern turntables keep the record spinning at a constant rate for both 30-centimetre and 18-centimetre records.

**Suspension**
A series of springs positioned beneath the turntable designed to provide stability to ensure smooth and accurate audio.

**Disc-size selector**
This needs to be specially set to accommodate the diameter of a record and is connected to the auto/manual operating lever.

**Cabinet**
The outer casing which houses the record-playing machinery is often made of top-quality wood, primarily for aesthetic purposes.

# World's most famous record

**Probably the most recognised record in the world – and beyond – is the Golden Record that was placed aboard the Voyager 1 and 2 spacecraft. They are two 30-centimetre copper phonographs plated with gold, and on them are recorded sounds, music and greetings from Earth in 55 languages, including Beethoven's *Fifth Symphony*, "Hello from the children of planet Earth" in English and the sound of crickets and frogs. They're encased in aluminium jackets and include a needle and cartridge along with instructions for any intelligent extraterrestrial life that happens upon Voyager on how to play the records. The records are designed to be played at $16^{2/3}$ revolutions per minute – half the speed of the $33^{1/3}$ standard for a commercial 30-centimetre vinyl. Since its launch in 1977, Voyager 1 has travelled over 22 billion kilometres, making the Golden Record one of the few humanmade objects to have left the Solar System.**

# A-Z OF THE ANCIENT GREEK OLYMPICS

## The modern Olympic Games may look very different, but the underlying ethos hasn't changed in millennia

The ancient heroic code was, as the epic poet Homer put it, 'to strive always to be the best, superior to others' – hence the modern Olympic motto: 'Faster, Higher, Stronger'. The ancient Greek world consisted of about 1,500 economically independent city-states, dotted around the coastlines of the Mediterranean and Black Seas, and these states were often at war with one another.

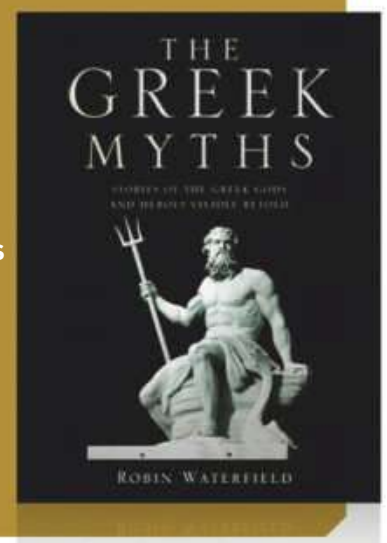
Nevertheless, they all thought of themselves as Greeks, and they invented sport – and from that international festivals such as the Olympic Games – as opportunities to test themselves against their peers without shedding blood – or not too much of it, at least. The games were even protected by a sacred truce so that competitors and spectators could travel in safety.

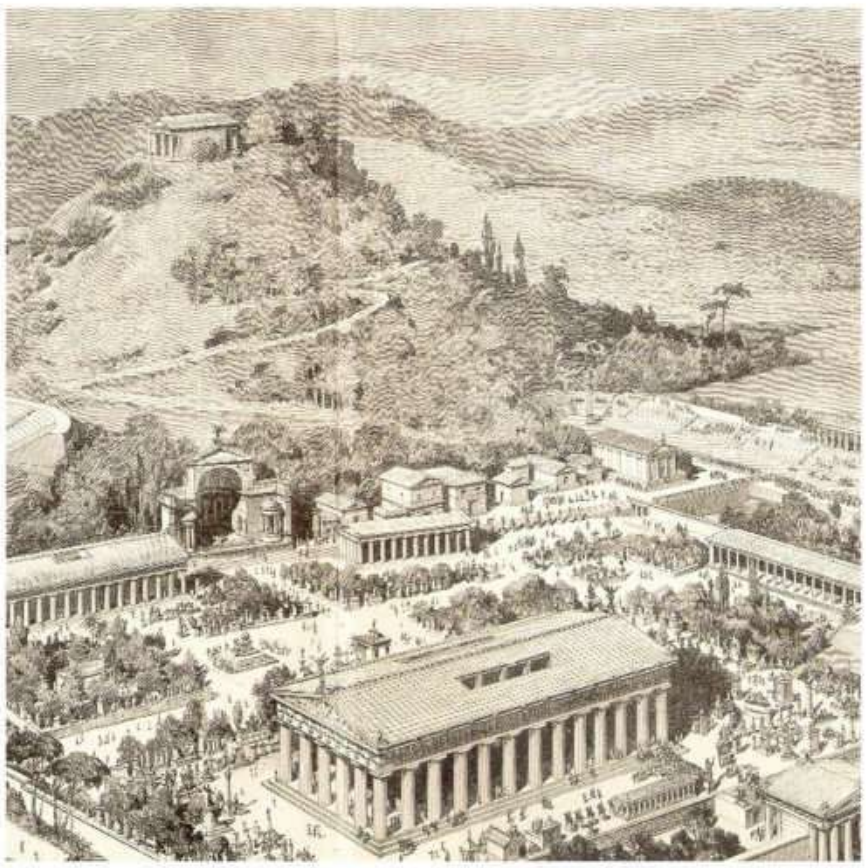
Every four years, thousands made their way to the Peloponnese, the southern peninsula of Greece, where Olympia was situated. Like today, athletes competed for a combination of individual and national glory. The origins of the games are lost in the mists of time. Like other games in ancient Greece, the Olympic festival probably began in celebration of the death of a local hero, perhaps Pelops himself, after whom the Peloponnese is named – literally 'the island of Pelops'.

The Greeks themselves said that the games began in 776 BCE, taking that year as the start of the first Olympiad. The year 2021 begins the postponed 32nd Olympiad of the modern era, since the competition restarted in 1896, but technically it begins the 699th Olympiad.

### The Greek Myths

***The Greek Myths*** **is a retelling of the timeless myths and legends of ancient Greece by renowned classicist Robin Waterfield and his wife, writer Kathryn Waterfield. Together they weave a vivid tapestry of the most unforgettable stories in all of human history. A catalogue of Greek myth in art through the ages, and a notable work of literature in its own right.**



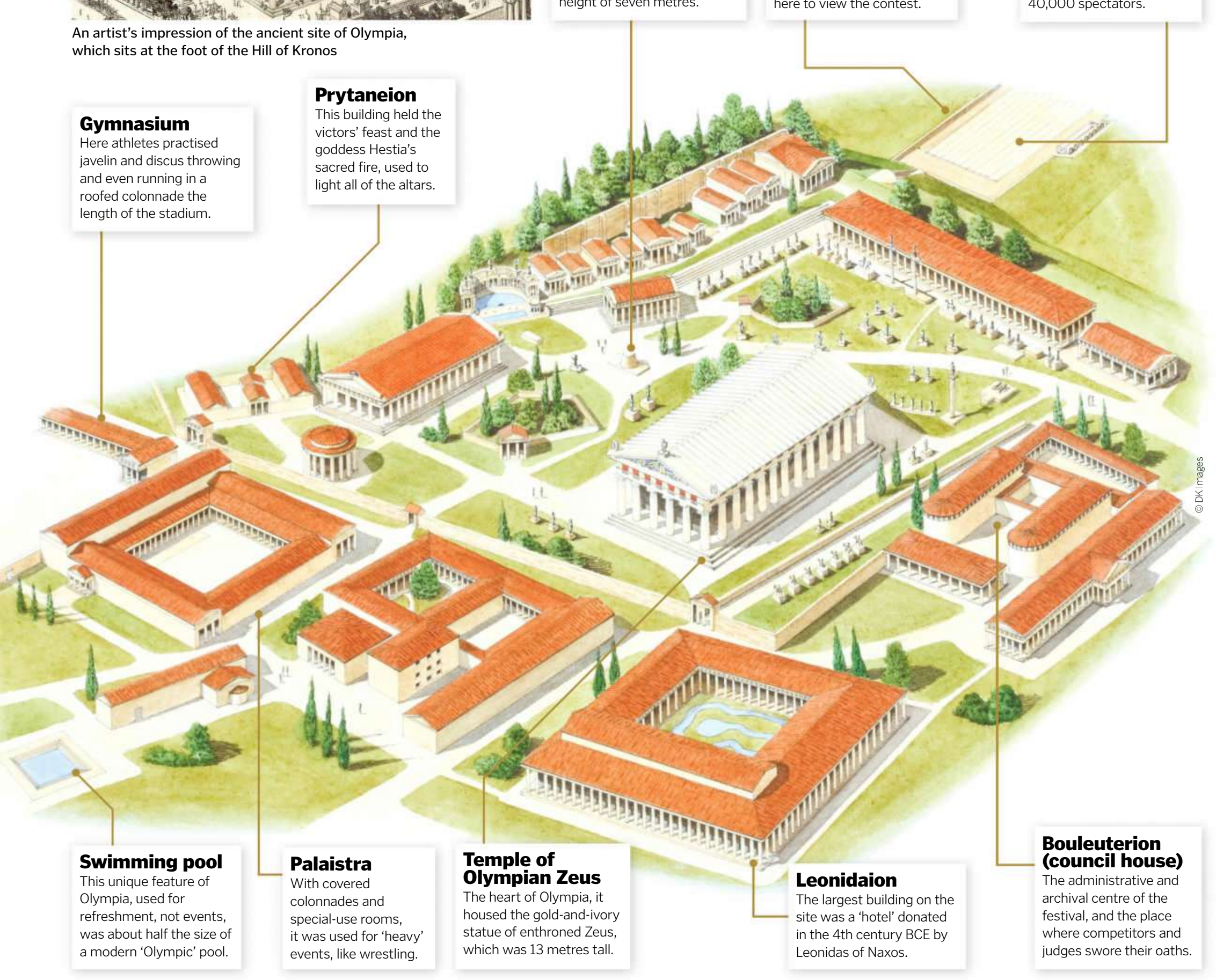


An artist's impression of the ancient site of Olympia, which sits at the foot of the Hill of Kronos

# Ancient Olympia

## The sacred enclosure and its landmarks

The Olympic Games, which were held from 776 BCE to 393 CE, were first and foremost a five-day religious festival dedicated to the glory of Zeus. Within the sacred enclosure – the Altis – were the spaces employed for the athletic competitions and worship of the gods, as well as for the ceremonies that took place during the festival. By the Classical period numerous buildings populated the area, and the stadium and hippodrome were enhanced. Most of what we see today has been excavated – in a joint venture between the Greek Archaeological Service and the German Archaeological Institute – since 1936.



**Great Altar of Zeus**
So many animals were sacrificed here that the ashes, congealed by fat, reached a height of seven metres.

**Altar of Demeter Chamyne**
Opposite the judges' stand, the only married woman permitted at the Olympics, Demeter's priestess, perched here to view the contest.

**Stadium**
Numerous events besides the all-important footraces were staged here; its embankments could accommodate up to 40,000 spectators.

**Gymnasium**
Here athletes practised javelin and discus throwing and even running in a roofed colonnade the length of the stadium.

**Prytaneion**
This building held the victors' feast and the goddess Hestia's sacred fire, used to light all of the altars.

**Swimming pool**
This unique feature of Olympia, used for refreshment, not events, was about half the size of a modern 'Olympic' pool.

**Palaistra**
With covered colonnades and special-use rooms, it was used for 'heavy' events, like wrestling.

**Temple of Olympian Zeus**
The heart of Olympia, it housed the gold-and-ivory statue of enthroned Zeus, which was 13 metres tall.

**Leonidaion**
The largest building on the site was a 'hotel' donated in the 4th century BCE by Leonidas of Naxos.

**Bouleuterion (council house)**
The administrative and archival centre of the festival, and the place where competitors and judges swore their oaths.

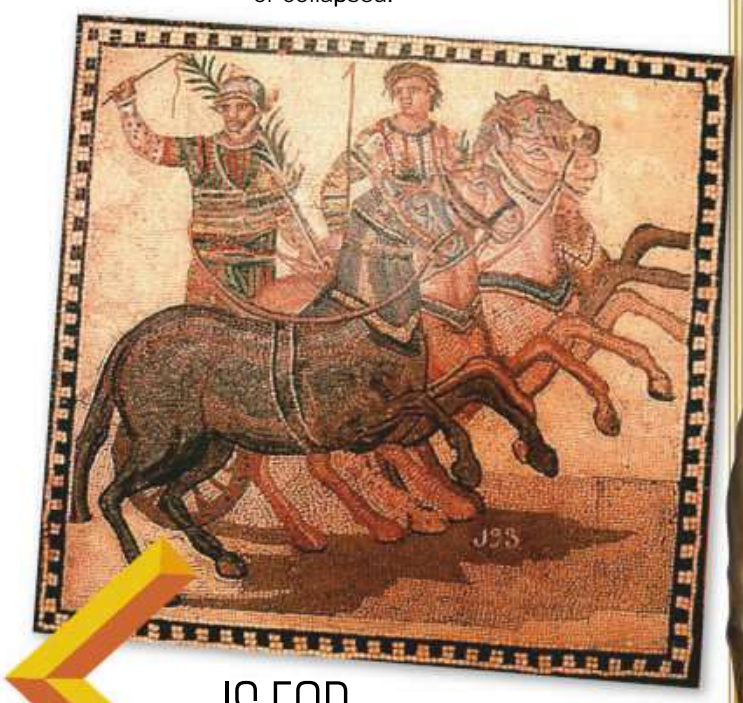
© DK Images

## A IS FOR... ALTIS

This is the enclosure, sacred to Zeus, where the Olympic festival took place. The Olympic Games were a religious festival, not just a sporting event, and the central event of the five-day games was a hecatomb – the enormously lavish sacrifice of 100 oxen at Zeus's altar.

## B IS FOR... BOXING

Although similar to modern-day boxing, the rules were not quite the same, above all because there were no rounds. Competitors just slugged it out, with their hands wrapped in strips of leather, in a ring formed of spectators until – maybe hours later – one man was knocked out or collapsed.



## C IS FOR... CHARIOT RACING

Chariot racing was extremely dangerous, and the wealthy owners trained slaves for all the equestrian events. The events involving chariots were held in the hippodrome, which was about 600 metres long. It was wide enough to allow up to 40 chariots to race at one time.

## D IS FOR... DIET

Ancient athletes recognised the importance of eating special foods for energy and muscle development; they even argued about whether one should abstain from sex while training. An athlete's diet was richer in meat than the normal Greek diet.

## E IS FOR... EVENTS

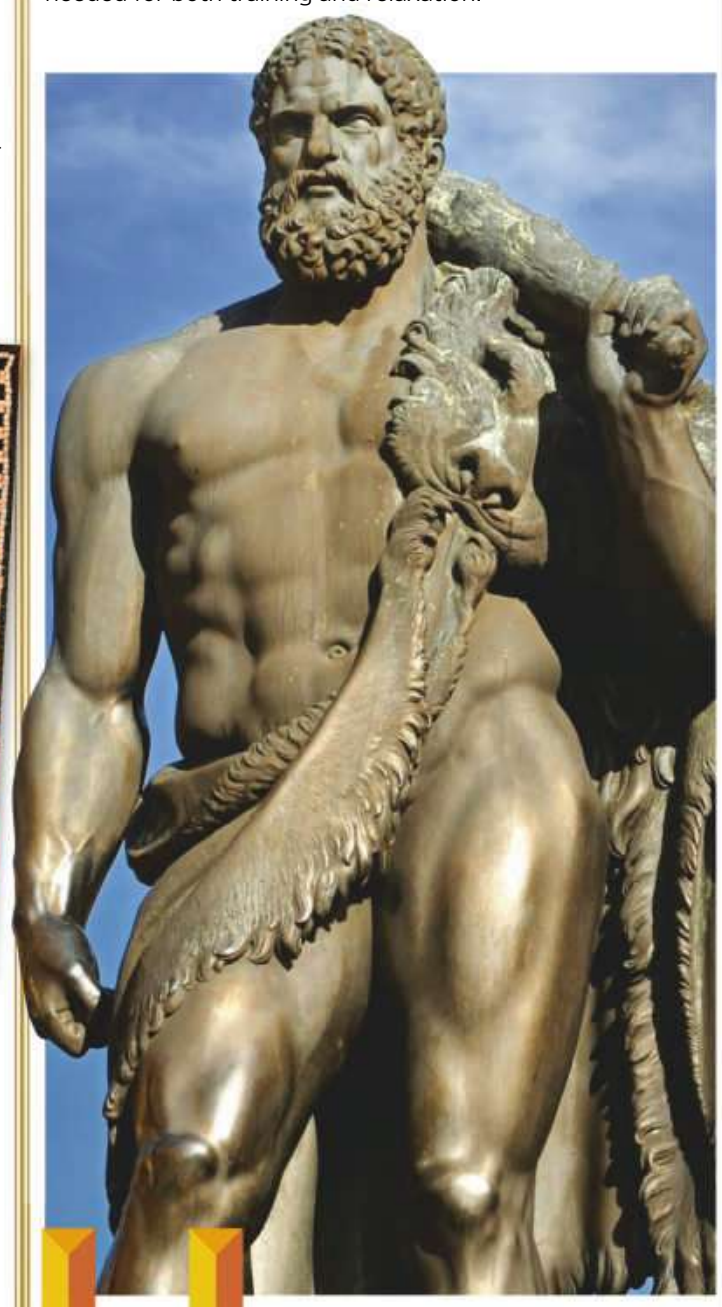
The only events were those considered suitable training for warfare: boxing, wrestling, pankration – a brutal ancient martial art with almost no rules – four running races, the pentathlon, chariot racing and several equestrian events.

## F IS FOR... FLAME

A conspicuous aspect of the modern Olympics is the ceremonial lighting at Olympia of the Olympic flame. This is said to commemorate Prometheus' mythical gift of fire to humankind, but in fact it had no ancient counterpart, and was first introduced for the 1928 Olympics held in Amsterdam.

## G IS FOR... GYMNASIUM

The gymnasium was simply a practice area. The actual events were held outdoors in the blazing heat of a southern Greek summer, but the Greeks were sensible enough to want to practise indoors. The Olympic gymnasium provided the athletes with all the facilities they needed for both training and relaxation.



## H IS FOR... HERACLES

The ultimate strongman, Heracles – who was known as Hercules to the Romans – is credited in one story with founding the Olympic Games. He filled his lungs and sprinted until he needed to draw breath again, and that spot marked the end of the stadium. Apparently he could hold his breath for approximately 200 metres.

## I IS FOR... INSCRIPTIONS

The Altis gleamed with statues of bronze and marble of famous athletes or dignitaries. But there was also a terrace of statues inscribed with the names of cheats, put up at their expense as a punishment. This was positioned so that athletes would see them as they entered the stadium.

## J IS FOR... JUGGLERS

The ancient Olympics were not merely an occasion for sport. In a carnival-like atmosphere, poets and orators declaimed, peddlers hawked their wares and jugglers and other kinds of performers offered entertainment. Spectators mingled in their thousands with contestants and their trainers, slaves and priests, alongside representatives from every walk of life.

## K IS FOR... KALLIPATEIRA

Having no surviving male relatives to train her son, Kallipateira of Rhodes trained him up herself, defying the strict ban on any female presence at the Olympics by disguising herself as a man. Her deception was discovered, however, when she leapt for joy at her son's success and exposed herself.

## L IS FOR... LENI RIEFENSTAHL

For the Berlin Olympics of 1936, Adolf Hitler had the filmmaker Leni Riefenstahl carve the five interlocked Olympic rings onto a stone to suggest that this was an ancient symbol, but in fact it was invented in 1913 to represent the five main regions of the world.

18+

# WHAT IS AVAXHOME?

# AVAXHOME-

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## M IS FOR... MILO

Milo of Croton – a Greek city in southern Italy – was perhaps the most famous athlete of the ancient world. He was a wrestler, and he achieved the astonishing feat of winning in six successive Olympics, once as a boy and five times as an adult.

## N IS FOR... NUDITY

For all the track and field events, the male contestants were nude. Genitals were tied back against the body with a leather string to minimise discomfort. Some spectators were even encouraged to rub the athletes' bodies with olive oil until they gleamed!

> *"Cheating was rare: the few events did not readily lend themselves to it, though officials could potentially be bribed"*

## O IS FOR... OATH

The spirit of the ancient Olympic oath was exactly the same as its modern counterpart – except that nowadays the oath is not administered over a slice of raw boar meat. The athletes swore to play fair, and the judges to judge fairly and not to divulge information about any of the contestants.

## P IS FOR... PENTATHLON

The pentathlon consisted of five events: discus, javelin, long jump, running and wrestling, which all took place in a single afternoon. Competitors often competed in the pentathlon as part of their military training, because each event was thought to be useful during a battle.

## Q IS FOR... QUADRENNIUM

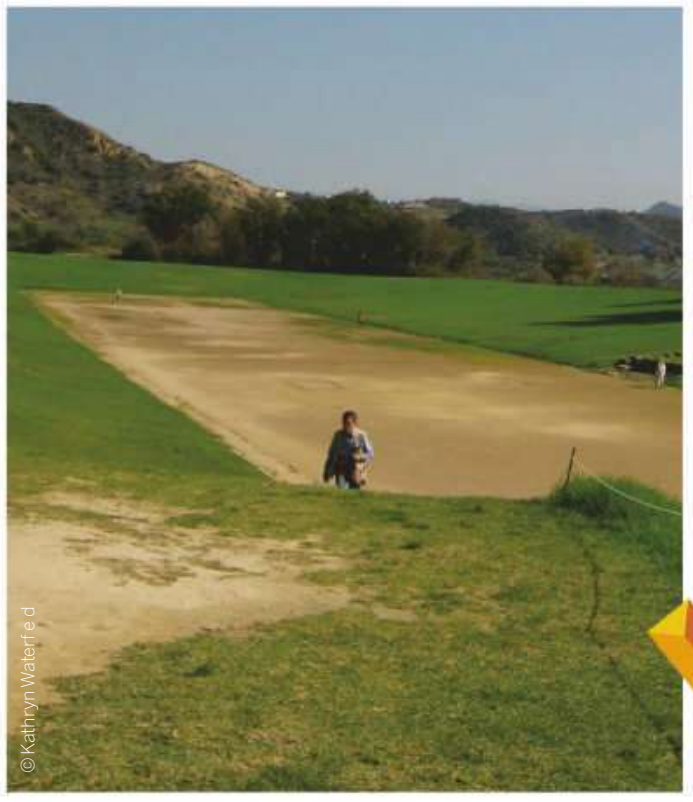
The Olympic Games were held, as now, every four years. The other most famous games – at Delphi, Nemea and Corinth – were four-yearly or two-yearly festivals, and were spaced so as not to clash with the Olympics, and so that athletes could attend a major festival in any given year.

## R IS FOR... RIBBONS

The prizes at the Olympic Games in ancient Greece were no more than ribbons – bands, intertwined with sprigs of wild olive, to wreathe the heads of the victors. The winner gained enormous prestige, and that was all – though that was sometimes enough to bring him fame and fortune back home, perhaps in the political arena.

## S IS FOR... STADIUM

The sandpit was the venue for wrestling, the hippodrome for equestrian events and the rest were held in the stadium, whose grassy banks could seat 40,000 spectators. The four footraces were one- and two-stade sprints, a 20-stade slog and a two-stade race run in armour.




## T IS FOR... TRAINING

The ancient Greek lifestyle guaranteed a basic level of fitness, but athletes also practised their specific events and cross-trained through dancing, for instance. All contestants also trained for the month preceding the games in the Olympic gymnasium.

## U IS FOR... UNDERHAND DEALINGS

Cheating was rare: the few events did not readily lend themselves to it, though officials could potentially be bribed. Despite having a range of medications, the use of performance-enhancing drugs doesn't seem to have been an issue.

## V IS FOR... VICTORY

The Greeks were not sportsmen in our sense: victory was all, and coming second counted as defeat. Nor were they interested in world records. Accurate measurement was difficult, so the focus was on beating your rivals in the immediate event.

## W IS FOR... WOMEN

Except for a single priestess and unmarried girls, women were not allowed into the ancient Olympics. But an all-female festival was organised at Olympia, just before or after the male games. Sacred to Hera, the goddess wife of Zeus, these games consisted of no more than a few footraces.

## X IS FOR... (E)XCELLENCE

Competition was a major part of an aristocrat's life – hence the importance of the Olympic Games. Only peers counted. Alexander the Great quipped, when asked if he'd enter the sprint: "Only if my opponents are also kings."

## Y IS FOR... YOUTH

Olympic events fell into three age categories: boys (aged 12 to 15), youths (16 to 18) and men (over 18). Success at Olympia could radically change a boy's life. He seemed to be destined for greatness, and back home he would be groomed to play a major part in his city's political life.

## Z IS FOR... ZEUS

Phidias' 13-metre-high gold-and-ivory statue of the enthroned god, housed in his temple at Olympia, was one of the Seven Wonders of the Ancient World. Zeus' altar, north of the temple, supposedly marked the spot where he struck the site with his thunderbolt, claiming it as sacred to his worship.

# How the slave trade ended

## Why the British Empire stopped these harrowing transatlantic shipments and their human cargo

**Safety net**
The ship's crew made escape difficult by placing nets around the ship's perimeter: less slaves at the end of their voyage meant less profit.

**Escape**
The brutal conditions on board and the knowledge of their destination made many desperate to escape. Some would try to jump off the ships mid-voyage. Those who died during the trip were thrown overboard.



© Getty

Slaves were often sent to work on tobacco, rice and cotton plantations, picking the luxury goods that they may have been sold for

**Beginning in the 1500s, the slave trade saw millions abducted from their homes and shipped against their will to endure a life of manual labour and mistreatment. Mainly targeting Africa, people were transported across the Atlantic to America, where they would be auctioned.**

**Having been split from their families, people were forced aboard cramped and disease-ridden ships for months. Life at sea involved brutal physical and emotional abuse, with around 15 per cent dying on the journey. Some feared losing their lives on board, while others feared the lives they were sailing towards, and were force fed by crew as they tried to starve themselves. Objectified and sold in a foreign land in exchange for goods such as cotton, sugar, tobacco and ginger, how could such an unjust and profit-driven operation continue for centuries? And how was this entrenched and barbaric system eventually banned?**

**When Britain explored other countries, encountering diverse and unfamiliar civilisations, instead of embracing these new cultures, Britons were much more interested in the available land and the people they could utilise for economic gain. The attitudes to race at the time meant that the government allowed this unjust treatment of innocent people. Because the slave trade was legal, those who protested against it needed to find a way to reach those in power to bring about change. It took a combination of enslaved activists and distant onlookers to battle to bring these centuries of torment to a close. As slaves spoke out about their own experiences and those in parliament began to acknowledge the barbarous practices involved, the laws on the trading of people were revisited.**

**When slavery was first abolished, no more slave ships were allowed to set sail. But this didn't include freeing those who were already held as slaves. It wasn't until 1838 that all slaves in the British Empire were granted freedom. None of them were given any form of compensation for a lifetime of anguish and torture, while owners were paid by the government for the loss of each slave.**

© National Maritime Museum, London

### 1562
John Hawkins captured 400 Africans in a violent conflict and traded them in the West Indies for pearls, ginger and sugar. He is the first known Englishman to have done this.

### 1713
The Treaty of Utrecht provided permission for Britain to import an unlimited number of slaves to the Spanish Caribbean.

© Getty

### 1728
The First Maroon War took place in the British colony of Jamaica. This involved the retaliation of slaves who had managed to escape.

© Getty

### 1765
After making friends with Jonathan Strong, a slave who was being badly beaten, Granville Sharp began to challenge the British slave trade.

### 1772
American Quaker John Woolman arrived in England to ask Quakers there to join him in support of his anti-slavery campaign.

# On board the slave ships

What was it like to travel as an item to be sold?

### Women and children
Often separated from the men, women and children had slightly more space, but being nearer the deck made them targets for abuse from the crew.

### Labour
Slaves were often forced onto the deck of the ship and made to exercise or carry out manual labour.

### Ships' design
To endure 12-month round trips in changeable conditions, the large ships had many sails and a complex rigging system.

### Below deck
Space was so cramped in the middle sections of the ship that people were forced to lie down or crouch so that everyone could fit.

### Bigger ships
In the early 18th century, slave ships were over 60 tonnes on average. Custom-built slave ships increased to 180 tonnes by the end of the century.

© Science Photo Library

## The anti-slavery movement

**Throughout Britain's involvement in the slave trade, there were always those who acknowledged the injustice that came with forcefully transporting, owning and selling other human beings. As slavery became more prevalent, more people let their disapproval be known.**

**Two of the most influential abolitionists were Thomas Clarkson and William Wilberforce. People had heard some stories of the conditions faced by slaves, but Clarkson spent time creating an in-depth study of the trade. Publishing his findings on how slaves were being treated worse than animals, he spread this vital knowledge. Travelling across Europe, he campaigned against these wrongdoings, creating a mass movement by recruiting supporters.**

**William Wilberforce played his part from inside parliament. Inspired by the work of Clarkson, he spent 18 years introducing anti-slavery motions in parliament. After much persistence, and many persuasive speeches, his case was won and the law was changed.**

© Getty

Thomas Clarkson often spoke at the Anti-Slavery Society as a lead campaigner

### 1772
It is ruled that slaves brought to England can't be forcibly removed and returned to where they were taken from.

### 1782
Letters written by Ignatius Sancho, who was enslaved as a young child, were published. This gave a first-hand account of the horrors he faced.

### 1791
Parliament rejects William Wilberforce's first bill to abolish the slave trade by 163 votes to 88.

© Schomburg Centre for Research in Black Culture

### 1791
The Haitian Revolution was led by Toussaint L'Ouverture as slaves in St Domingue revolted. This involved burning plantations growing the sugar used for trades.

### 1804
St Domingue became the Republic of Haiti. This was the world's first black-led state to be declared outside of Africa.

© Josiah Wedgwood

### 1807
Parliament passed An Act for the Abolition of the Slave Trade, meaning is was illegal to buy slaves. The Slavery Abolition Law was made law in 1833.

Wilhelm Röntgen was a mechanical engineer and physicist

A museum dedicated to Wilhelm Röntgen can be found in his hometown, Remscheid

© Getty

## A life's work

**The mechanical engineer's route to an unlikely discovery**

**1845**
On 27 March, Röntgen was born in Lennep, Prussia, now Remscheid, Germany.

**1848**
When he was three years old, Röntgen moved to Apeldoorn in the Netherlands with his family.

**1862**
He started at the Utrecht Technical School, but was later expelled after being accused of playing a prank that another student had committed.

**1869**
Graduating from the University of Zurich, Röntgen earned a PhD in experimental physics.

# Wilhelm Röntgen

## This man's accidental discovery provided medicine with a vital tool for diagnosing disease

Born an only child into a family of cloth merchants and traders, Wilhelm Conrad Röntgen was set to follow a different career to the trade passed down through generations of his family.

Despite his eventual global recognition as a scientific mastermind, this wasn't necessarily the impression he gave out during his time in education. He was known to miss classes, and for much of his time at university would rather be outside exploring than inside studying. Luckily a professor helped him to understand the importance of his exams, and Röntgen attained the degree that those close to him thought he wouldn't manage to achieve.

His scientific interests would come in his own time – after leaving school he became interested in studying a range of topics. These included investigating the properties of gases, the compressibility of water and the magnetic effects of dielectric materials. These are materials that are poor conductors of electric current, so almost no current flows through them when placed in an electric field. Instead their positive and negative charges are displaced.

However, the crucial study that would see him go down in the history books, as well as transform the future of medical technology, were his findings in the field of radiology.

As an unexpected result of another experiment that focused on passing a current through gases, Röntgen encountered X-ray radiation. These previously undocumented electromagnetic waves captured the attention of the scientist. How could this radiation show the insides of certain objects?

Leaving his original experiment, Röntgen began to explore the variety of materials this unfamiliar form of radiation could pass through. Being highly energetic, what he discovered was that X-rays can pass through most solid materials, from soft human tissue to plastic and leather, but are blocked by harder materials like metal and human bone.

The applications of his discovery almost immediately changed the way medical professionals examined bodies. Within one year of Röntgen releasing a paper on his findings, titled *On a New Kind of Rays*, the first radiology department was established in Glasgow Hospital. This new department soon developed X-ray images of objects such as kidney stones and even a coin that was stuck in a patient's throat. Röntgen had given doctors a greater vision of their patients and allowed them to make faster diagnoses.

*"Röntgen had given doctors a greater vision of their patients"*

### THE BIG IDEA

## Spotting X-rays

**It was in 1895 that Wilhelm Röntgen made his biggest contribution to science. While he was experimenting with passing electric currents through a glass tube, he noticed that a screen of barium platinocyanide placed near the experiment glowed softly. Röntgen came to the conclusion that when the electrons hit the tube, a form of radiation could move across the room to cause this reaction. He would later find that these invisible rays were also able to travel through a variety of materials, including paper, wood and aluminium. Unaware that the rays he had witnessed were closely related to light, he initially called the discovery X-radiation. Among his first X-ray images was one of the bones inside his wife's hand.**

This is one of the images Röntgen produced of his wife Anna Bertha Ludwig's hand

## FIVE THINGS TO KNOW ABOUT...

### WILHELM RÖNTGEN

**1 Getting into university**
In 1865, Röntgen managed to gain a place at the Federal Polytechnic Institute in Zurich to study mechanical engineering without having the required grades.

**2 Kundt's assistant**
At university, Röntgen worked in the laboratory of German physicist August Kundt, becoming his assistant. Kundt designed a method to measure the velocity of sound in solids and gases.

**3 Honorary degree**
Having made the discovery of X-rays, Röntgen was awarded an honorary Doctor of Medicine degree from the University of Würzburg.

**4 Engineering talent**
Röntgen wasn't deemed especially talented throughout school, but he had a mechanically tuned brain that allowed him to build devices to experiment with.

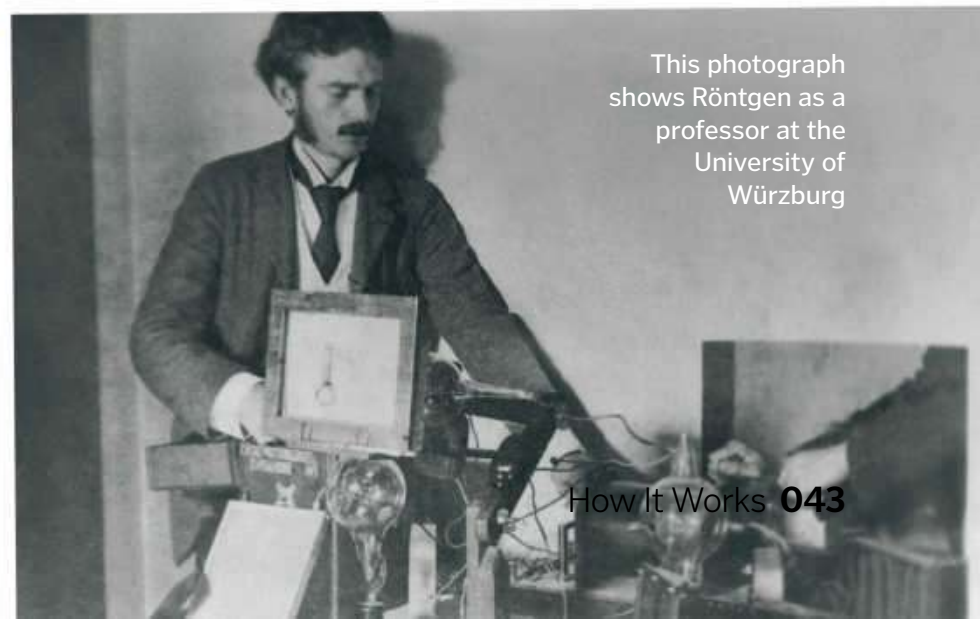
**5 Baring his bones**
Röntgen discovered what X-rays were capable of when he walked into the path of an X-ray beam and was able see his own bones.

**1876 to 1900**
Röntgen became the professor of physics at the universities of Strasbourg in 1876, Giessen in 1879, Würzburg in 1888 and Munich in 1900.

**1896**
Röntgen earned the Rumford Medal of the Royal Society of London.

**1901**
He received the first Nobel Prize in Physics after his X-ray discovery.

**1923**
On 10 February, Wilhelm Röntgen died due to colorectal cancer.



This photograph shows Röntgen as a professor at the University of Würzburg

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# SEA MONSTERS

**What makes these animals some of the world's deadliest underwater hunters?**

Words by **Ailsa Harvey**

Beneath the waves, millions of battles are taking place. Each sea-dwelling soldier uses their unique features to their advantage, with no two playing an identical game. In the diverse underwater world, an easy meal for one species could be another's biggest threat.

From the ocean's shallow shores to its dusky depths, over 200,000 different species dwell. For the majority of these animals, each day holds the possibility of being their last. They could be eaten at any moment, even while searching for their own food. Whether it's a whale using its sheer size as its weapon, or the refined tactics that help smaller species conquer, the sea is full of expert hunters.

How can an animal avoid doom when its enemies emerge from the murk? Though some predators attack unexpectedly, preying on a single oblivious target, other times sea creatures are aware of imminent danger and perform sneaky survival strategies. Swarming in massive schools, some fish are able to swerve chaotically together in the water, distracting a hunter's gaze from a single target. The predator will almost always leave with a meal, but each individual fish has a higher chance of swimming free. Others hide and disguise themselves to throw the threat off their tail, but one step out of line and the predator has won.

Most marine life lives in the upper half of the sea, with hunting options becoming sparse in the deepest zones. Where food is more challenging to find, hunters have evolved to execute hunts more masterfully, with songs and light displays. The ocean is proof that even the most beautiful creatures can be the deadliest monsters.

# TOP OF THE FOOD CHAIN

## Killer whales vs great whites

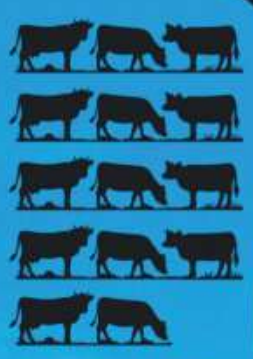
### How do two of the largest ocean predators compare?

**Orcas and great white sharks sit at the top of the food chain. These rulers of the sea eat with ease, but with contrasting hunting techniques and individual strengths, how would the two fare against each other? These apex predators have enough on the menu, but if it came to a battle to the death, evidence shows an orca might just take the win. In the past, examination of great white carcasses found in the water or washed ashore have shown some to have a missing liver, with wounds that correlated to an orca's bite.**

**9.6 metres**
Killer whales can grow longer than a London Bus.

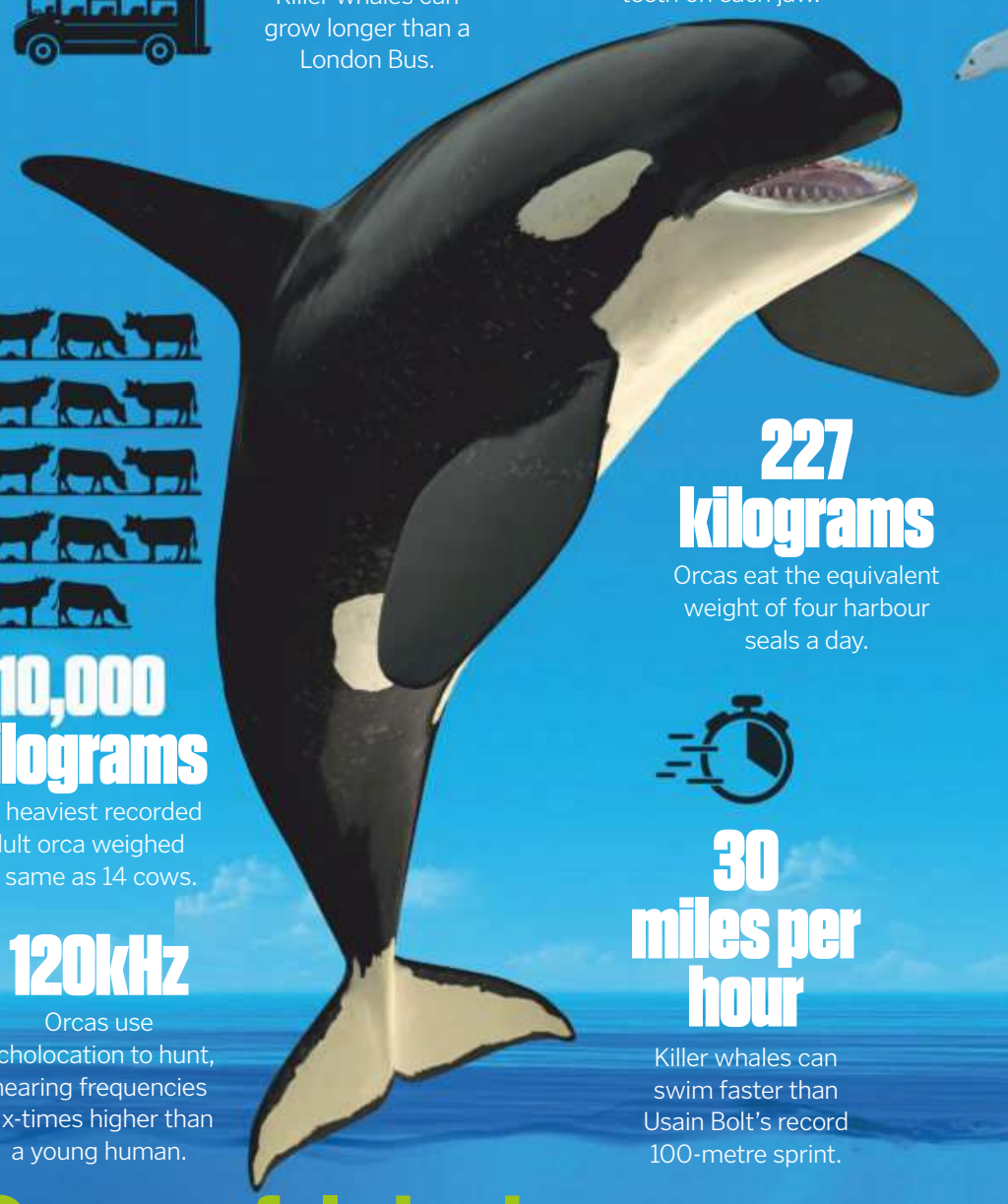
**40**
They have about 20 teeth on each jaw.

**6.4 metres**
The sharks can grow three-quarters the length of a London Bus.



**10,000 kilograms**
The heaviest recorded adult orca weighed the same as 14 cows.

**120kHz**
Orcas use echolocation to hunt, hearing frequencies six-times higher than a young human.



**227 kilograms**
Orcas eat the equivalent weight of four harbour seals a day.



**30 miles per hour**
Killer whales can swim faster than Usain Bolt's record 100-metre sprint.



**Three miles**
Great whites can detect tiny volumes of blood in the water from afar.

**300**
Hundreds of sharp, triangular teeth are arranged in several rows.

**Three metres**
Great whites can jump high out of the water when chasing seals.

**2,268 kilograms**
Great whites can be as heavy as three-and-a-half cows.

**28 miles per hour**
They have an impressive top speed when chasing prey.

**9,900 kilograms**
Each year these sharks eat over four times their own body weight in food.

## Successful sharks

© Getty

### Bull shark
**Max size:** 3.5 metres
**Speed:** 11 miles per hour
**Main prey:** Bony fish and small sharks

Using the bump-and-bite technique, a bull shark will headbutt and snap at its victim until it is unable to move.

© Getty

### Oceanic whitetip
**Max size:** Four metres
**Speed:** Six miles per hour
**Main prey:** Bony fish and squids

Being relatively slow sharks, oceanic whitetips will swim near the top of the water, spying on potential prey below.

© Getty

### Shortfin mako
**Max size:** 3.8 metres
**Speed:** 35 miles per hour
**Main prey:** Squid and bony fish

The fastest shark will usually swim at high speeds in a figure of eight before it hurtles towards its prey with its mouth open.

© Getty

### Tiger shark
**Max size:** 7.6 metres
**Speed:** 20 miles per hour
**Main prey:** Fish, stingrays, seals and squid

Eating almost anything they can hunt, they repeatedly climb and dive as they swim, searching a wider area.

# VICIOUS VENOM

## Toxic attackers

### How these aquatic assassins catch dinner

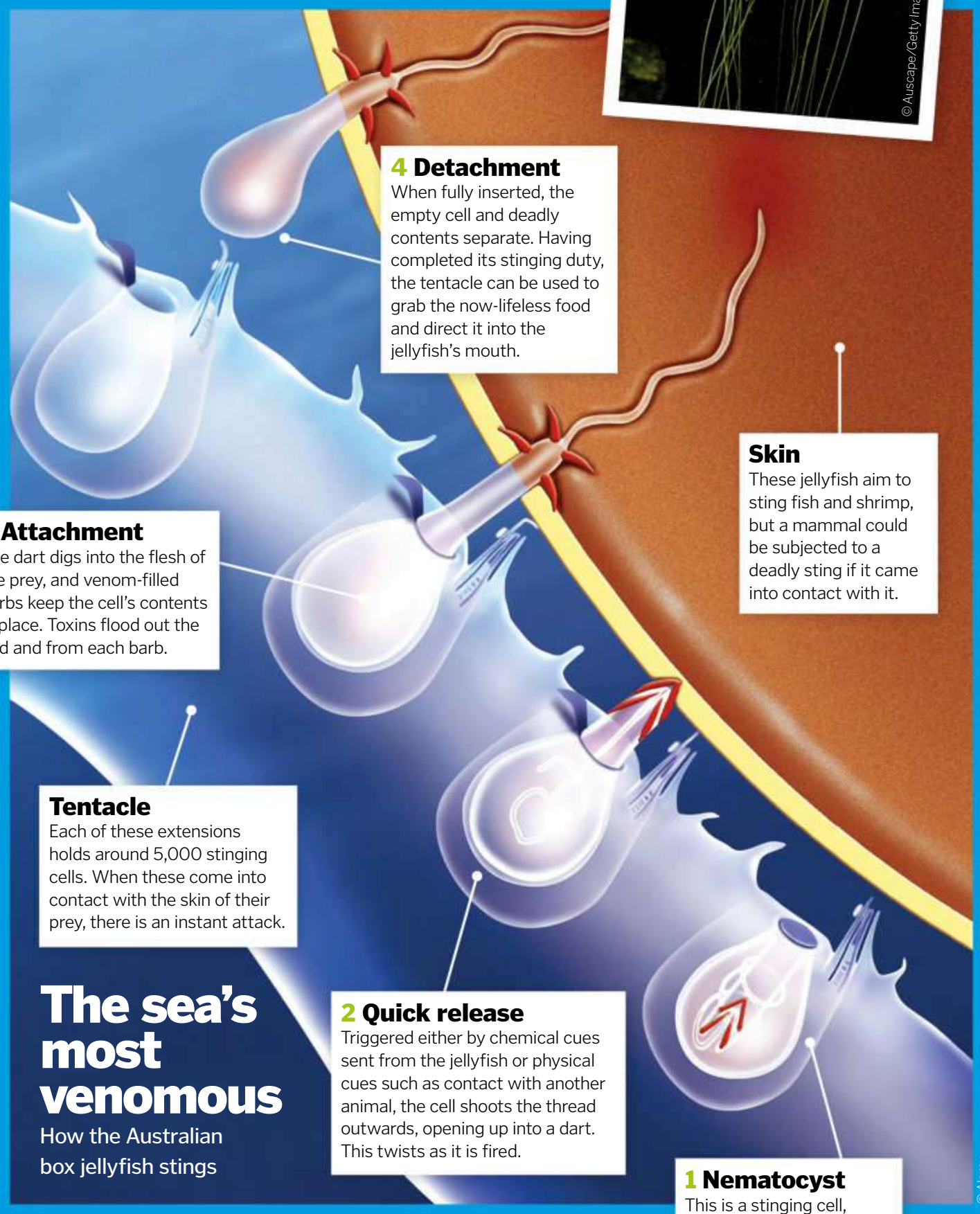
**From snakes and stonefish to octopuses and sea slugs, many hunters of the sea use venom to immobilise or kill their prey. A hunting octopus, for example, can either release venom into the surrounding water, or create a wound with its mouth to direct the poison straight into their victim's body.**

**Of all the toxic creatures in the ocean, the most venomous have no sharp tools. They drift brainless and transparent through the water and can look deceivingly unthreatening, like the Australian box jellyfish. Below their cubic bodies, three-metre-long tentacles dance in the water. It is these lacy extensions that need to be avoided by animals who wish to stay alive. The jellyfish needs to kill with venom before eating its victim, otherwise its soft body risks being torn apart by the desperate animal. One thing which makes this species more dangerous than other jellyfish is their ability to swim rather than float with the tide. This means they are more difficult to avoid, especially as they have clusters of eyes to observe their surroundings with.**

*"Of all the toxic creatures, the most venomous have no sharp tools"*

Australian box jellyfish are found in the warmer waters surrounding Australia

© Auscape/Getty Images


4 Detachment
When fully inserted, the empty cell and deadly contents separate. Having completed its stinging duty, the tentacle can be used to grab the now-lifeless food and direct it into the jellyfish's mouth.
Skin
These jellyfish aim to sting fish and shrimp, but a mammal could be subjected to a deadly sting if it came into contact with it.
3 Attachment
The dart digs into the flesh of the prey, and venom-filled barbs keep the cell's contents in place. Toxins flood out the end and from each barb.
Tentacle
Each of these extensions holds around 5,000 stinging cells. When these come into contact with the skin of their prey, there is an instant attack.
The sea's most venomous
How the Australian box jellyfish stings
2 Quick release
Triggered either by chemical cues sent from the jellyfish or physical cues such as contact with another animal, the cell shoots the thread outwards, opening up into a dart. This twists as it is fired.
1 Nematocyst
This is a stinging cell, designed to paralyse prey. Coiled inside this spherical capsule is a barbed thread which injects venom.

© Alamy

## Australia's aggressive 'salties'

**Saltwater crocodiles lurk along the coastline of Australia and are the largest of all crocodiles and alligators on the planet. But it isn't purely their size that makes them such ferocious predators. Their snapping set of sharp teeth and frequent displays of aggression put any animal in danger when approaching their territory. This includes humans.**

**Saltwater crocodiles are difficult to see, as they hide just beneath the water's surface. They can burst from their resting place to tear apart sea creatures as high up in the food chain as sharks. They also snack on birds resting or flying near the surface, and they can pounce on land dwellers with their fast-moving legs, charging out of the water at speeds of over 26 miles per hour. From top to bottom these armoured beasts are equipped for a fight, and can often be seen using their tails as a thrashing weapon.**

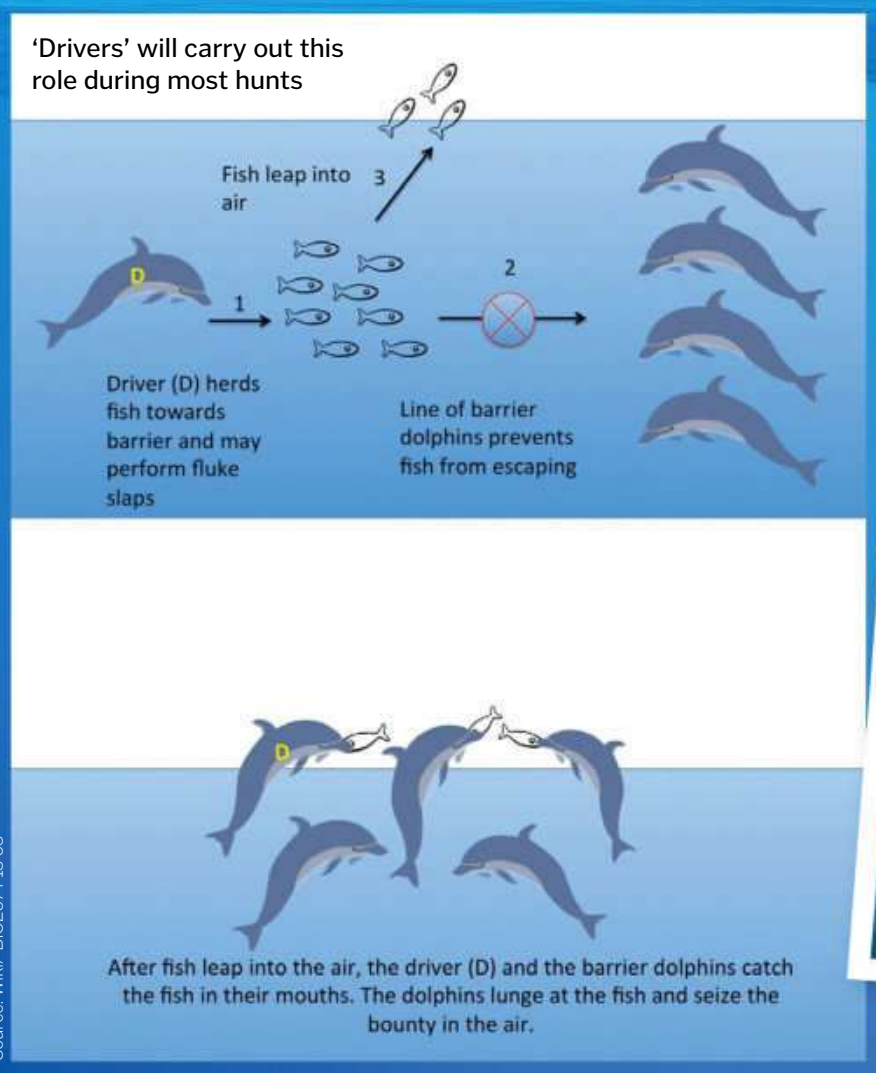
Saltwater crocodiles' teeth can be up to 13 centimetres long

© Getty Images/ Bernard Radvaner

# TACTICAL TEAMWORK

## How animals hunt in teams

**Greater numbers doesn't always mean greater reward, as some marine species work best alone in sneaking up unseen. However, others use larger numbers to surround and control their prey. Bottlenose dolphins, for example, have allocated roles. Groups have been seen sticking to the same jobs each time food is required, with all their cooperative hunting involving 'drivers', which shepherd schools of fish into a suitable area, and 'barriers', which block the fish and steer them to the surface. Other groups have more complex strategies, requiring more jobs.**


'Drivers' will carry out this role during most hunts
Fish leap into air
3
D
1
2
Driver (D) herds fish towards barrier and may perform fluke slaps
Line of barrier dolphins prevents fish from escaping
D
After fish leap into the air, the driver (D) and the barrier dolphins catch the fish in their mouths. The dolphins lunge at the fish and seize the bounty in the air.

Source: Wiki/ BIO267 F13 03

*"Others use larger numbers to surround and control their prey"*

Barracuda trap smaller fish by circling around them in groups

## Interspecies attack

**A group of the same species teaming up on their prey is a common occurrence in the wild ocean, but in some rare cases, two individuals from different species can attack their prey together. This plays on the different strengths of the animals to make their hunting game much more efficient.**

**The first observed example of this is the relationship held between the moray eel and the grouper fish. To begin, communication needs to take place between them. Initiating the hunting, a grouper will swim over to an eel, shaking its head and wiggling its fins. The moray eel knows that this is a friendly invitation for a hunt, and the eel may decide to follow the fish.**

**Smaller reef fish will usually hide from groupers by swimming within the corals, and will avoid eels by darting out into the open water. By working together, the grouper can direct prey into the coral for the eel, while the eel can do the opposite, providing food for the grouper. This method is around five-times more effective for both the animals than hunting alone, and because they swallow the fish whole, there is no fighting over scraps.**

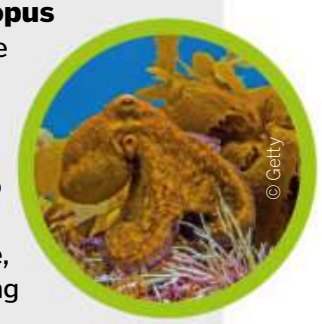
The grouper (left) and moray eel (right) seem unlikely hunting partners

## 5 FACTS ABOUT UNIQUE TECHNIQUES

**1 SHOCKING Electric ray**

With tactics to defend themselves and to catch their prey, these rays have electric muscle cells that can deliver 400 rapid electric shocks in a row, each containing 45 volts.

**2 TRICKING Octopus**




Blending into the background, prey swim right up to them. They have even been known to tap prey on the back with a tentacle, sending them darting straight into their open mouths.

**3 SHOOTING Archer fish**

Residing in estuaries, these small fish don't appear too threatening, but they target unsuspecting prey outside the water. Making a barrel with the tongue, they close their gills and shoot water at branches above the surface, aiming for beetles and other insects to knock down and eat.

**4 PUNCHING Mantis shrimp**

Using their advanced eyesight, seeing more colours than any other species, they pinpoint a target. Then they punch with hammer claws, 50-times faster than humans can blink. This heats the surrounding water to the temperature of the Sun's surface for a moment.

**5 GLOWING Scaleless dragonfish**

This fanged fish lurks in the depths of the ocean, occasionally lighting up with bioluminescent cells that span the length of its body. Attracting other fish with its display, once a meal gets a bit too close, its long teeth bite down.

# Rocky shores explored

## There's marine wildlife in every nook and cranny of the coast, just waiting to be discovered

This is home to many animals, including stalked jellyfish, blue-rayed limpets and a whole host of fish

© Sally Sharrock

**A good place to hide**
Check under rocks and boulders, on and under seaweed, in crevices, overhangs and in rock pools to find animals.

**Snakelocks anemone**
Found low on the shore, by night they shine fluorescent green due to a special protein in their tentacles.

Devil crabs, sea lemons and hares, squat lobsters and snakelocks anemones are just some of the things you might be lucky enough to see when exploring rocky shores around UK coastlines. There is something really special about heading to the shore not knowing what might be tucked away, lurking under rocks, seaweed and crevices. But you need to know where to look and what you're looking for, otherwise you could miss more than you spot.

Did you know the beach is divided into three main parts? There's the upper, middle and lower, with surprisingly different inhabitants in each neighbourhood, all with special adaptations to live there. What you see on the shore will give you clues to where you are, hints to the best places to find creatures and what they are.

From a distance the upper shore looks like a pretty barren place to live, with dull browns, greys and greens, but the animals found here are rock hard. Acorn barnacles, limpets and sea snails called periwinkles can live here quite easily, grazing the rocks and battling the elements. They have one main aim: not to dry out. Inhabitants must do all they can to survive out of water. The middle shore is full of richness, vibrant colour and packed with exciting finds: an abundance of crabs like the green shore crab, beadlet anemones, edible seaweeds and seaweeds that smell like pepper.

If you want to see some really cool stuff, try to get out when the tide is really low to see serrated wrack and velvet swimming crabs – called devil crabs because of their red eyes – that can give quite a nip to the fingers. But the most amazing kelps live here too. With wavy fronds that look like underwater trees, they're often referred to as kelp forests.

© Alamy

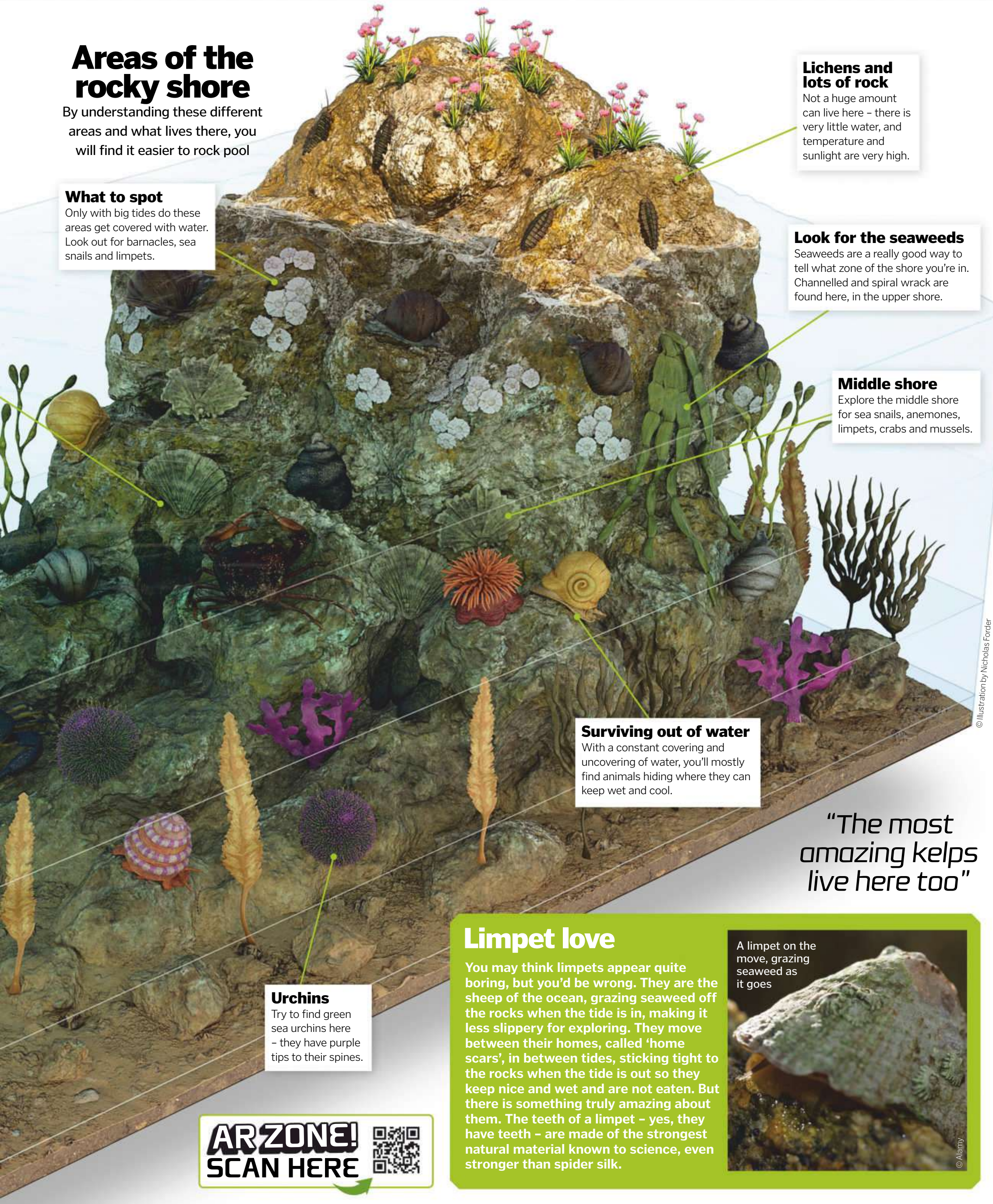
Beadlet anemone catching food in a rock pool

## Middle-shore madness

**This is a zone you may have stumbled across before, and is full of a variety of different animals and plants. But with more species all in one area comes a battle for space and food. It's home to really beautiful anemones like beadlet and also daisy anemones, which often cover themselves with fragments of shell and sand. Despite them being just a blob, beadlet anemones are far more complex than they look. They can get very angry if something invades their space – you wouldn't want to mess with one. If another comes too close, it will be harassed until it either goes somewhere else, or falls off the rock. If you see them out of the rock pools, you won't be able to see their tentacles, which they use to catch food – they will be tucked away as a strategy to avoid drying out.**

# Areas of the rocky shore

By understanding these different areas and what lives there, you will find it easier to rock pool



### What to spot
Only with big tides do these areas get covered with water. Look out for barnacles, sea snails and limpets.

### Lichens and lots of rock
Not a huge amount can live here – there is very little water, and temperature and sunlight are very high.

### Look for the seaweeds
Seaweeds are a really good way to tell what zone of the shore you're in. Channelled and spiral wrack are found here, in the upper shore.

### Middle shore
Explore the middle shore for sea snails, anemones, limpets, crabs and mussels.

### Surviving out of water
With a constant covering and uncovering of water, you'll mostly find animals hiding where they can keep wet and cool.

### Urchins
Try to find green sea urchins here – they have purple tips to their spines.

© Illustration by Nicholas Forder

*"The most amazing kelps live here too"*

**AR ZONE! SCAN HERE**

## Limpet love

**You may think limpets appear quite boring, but you'd be wrong. They are the sheep of the ocean, grazing seaweed off the rocks when the tide is in, making it less slippery for exploring. They move between their homes, called 'home scars', in between tides, sticking tight to the rocks when the tide is out so they keep nice and wet and are not eaten. But there is something truly amazing about them. The teeth of a limpet – yes, they have teeth – are made of the strongest natural material known to science, even stronger than spider silk.**



A limpet on the move, grazing seaweed as it goes

© Alamy

# The mystery of ball lightning

## What's the most plausible explanation for this rare atmospheric phenomenon?

It's a weather phenomenon that has puzzled the minds of scientists for thousands of years. As far back as the ancient Greeks, there have been eyewitness accounts of floating, glowing balls of electricity emerging after a thunderstorm. These balls of energy have ranged from the size of a golf ball to a few metres wide. There have even been reports of the plasma-like balls floating in the sky and entering people's homes before vanishing.

Explanations for these electrical oddities vary, but one of the only theories to be proven in a laboratory is the theory of vaporised silicon. In the ground, soil and sand have high quantities of silicon dioxide. When this compound is heated by the energy emitted by lightning it creates balls of light, which could explain ball lightning sightings in nature. However, this does not account for the witness reports of ball lightning passing through windows and entering a building before dissipating.

There may not be a one-size-fits-all answer when it comes to explaining ball lightning. It is possible that there are many different types of this phenomenon, each caused by a different process. The main hurdle for researchers is the infrequency of ball lightning events, making them difficult to study.

Ball lightning could be the result of superheated earth entering the atmosphere

© Alamy

## Ball lightning explained

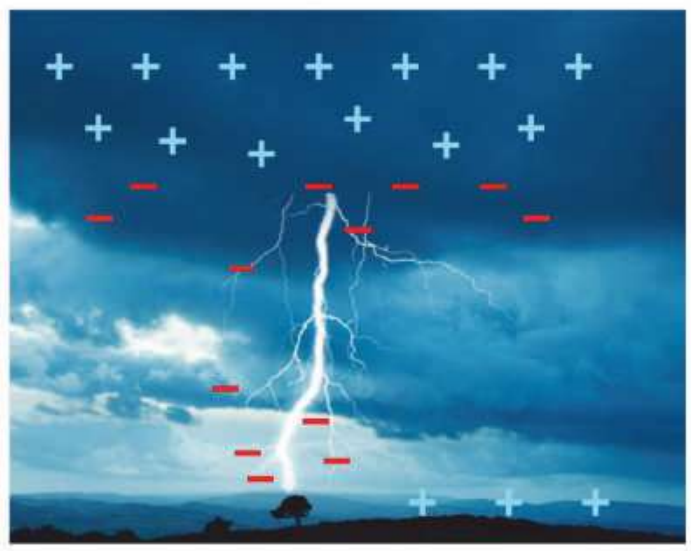
Here's how a lightning bolt is made and how it can create balls of light

### 1 Cloud batteries

When large clouds are formed in the air, charged water particles separate. The positively charged particles move to the top of the cloud and the negative particles fall to the bottom.

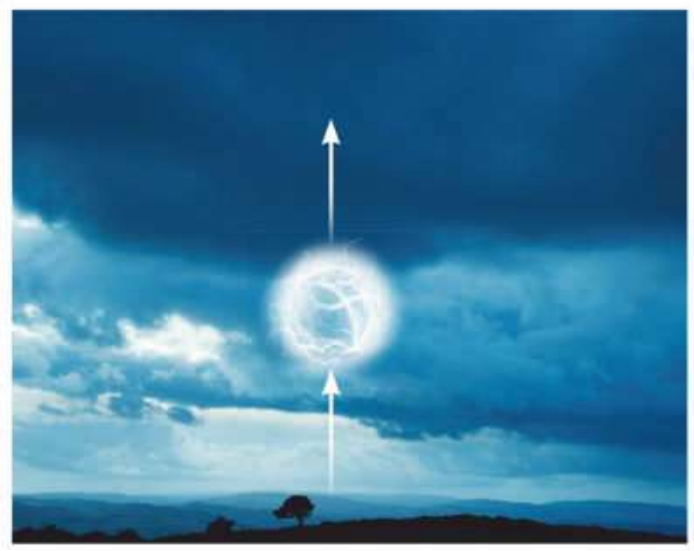
### 2 Generating a connection

The ground is positively charged and attracts the negative charge at the base of the cloud. A channel of ionised air forms from the cloud down and ground up. When they meet, they create an electric connection.



### 3 Unleashing lightning

When a connection between the ground and the cloud forms lightning strikes, heating the air to 30,000 degrees Celsius, over five times the temperature of the Sun's surface.



### 4 Stripping silicon

This extreme temperature strips oxygen from the silicon dioxide in sand and soil on the ground and superheats the vaporised silicon into a gas bubble.

© Getty

### 5 Forming bright light

As it cools and recombines with atmospheric oxygen the process generates energy and emits light, appearing as a ball of lightning.

## Is it all in your head?

**Some studies have concluded that ball lightning sightings are the result of magnetic field-induced hallucinations. During a thunderstorm, strong magnetic fields are created that can stimulate the brain's visual cortex. In studies using a transcranial magnetic stimulator – a non-invasive machine that delivers targeted magnetic fields into the brain – it was found that test subjects saw moving lights reminiscent of ball lightning reports. However, the range of colours sighted in the field, including blue, green and orange, vary more, whereas study participants only see white or grey light. Hallucinations are just one of many theories, but the mystery of ball lightning may be the collective effect of many different factors.**

Source: Wiki / Binadot

Many people have claimed to have witnessed balls of light travelling into their homes

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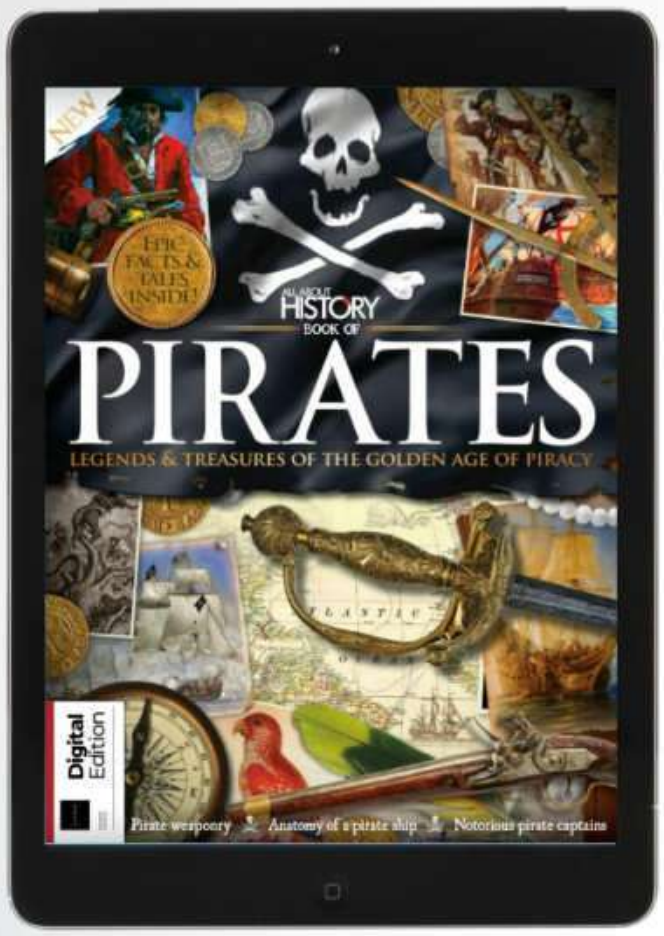
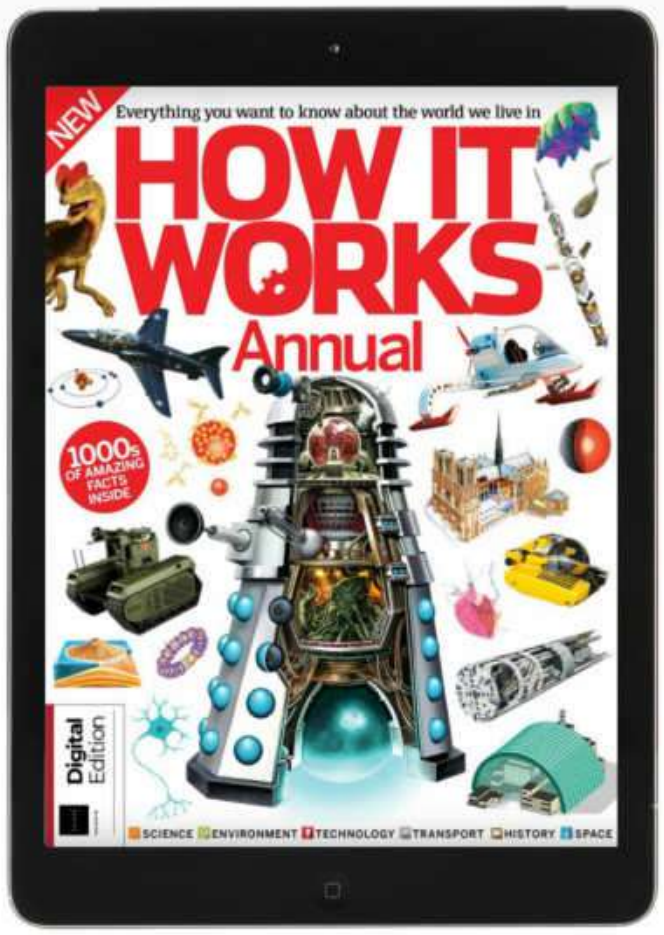



## Book of Pirates

In the 17th and 18th centuries, sailing was a risky undertaking. Ruthless pirates lurked on the horizon, craving wealth and reputation. In the **All About History Book of Pirates**, we cover everything you need to know about the legendary Golden Age of Piracy. Uncover the true stories of the bloodthirsty buccaneers who made their fortune plundering the high seas, from Captain Kidd and Edward 'Blackbeard' Teach to female pirates Anne Bonny and Mary Read.




## How It Works Annual

Welcome to the tenth volume of the **How It Works Annual**, where your burning questions about exactly how the world ticks finally get answered. Feed your mind, indulge your curiosity and uncover the truth behind some of the most popular misconceptions. Explore topics from science, technology, the environment, space and more. We delve deep into the mysteries of our universe with in-depth and entertaining articles accompanied by cutaways, illustrations and incredible images.

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# AMPHIBIOUS VEHICLES

Discover vehicles that can jump between land, water and air as a result of some innovative engineering

The dream of a fully functional amphibious vehicle dates back to the mid-1700s, when an Italian prince drove a modified land/water coach into the Tyrrhenian Sea. Since then, despite the peculiar universal desire to drive our cars into the nearest lake, only the Amphicar, a steel beauty with stylish tailfins, achieved anything close to commercial success, selling about 3,878 units in the 1960s.

Other 'amphibians' have had greater success – namely amphibious aircraft. That's because a simple amphibious plane or helicopter can be made by adding sturdy floats to a pair of landing skids. But amphibious land and water vehicles face many more obstacles, because the engineering rules of the water are often in direct conflict with the rules of the land.

For example, a high-speed watercraft needs to break the plane of the water to reduce drag. Picture the wide, hydrodynamic shape of a speedboat hull, which lifts the nose of the boat up and out of the water. The body of a sports car, on the other hand, needs to be low and flat to reduce drag and safely hug the road during sharp turns. So how do you engineer the body of a vehicle that can navigate both surf and turf with ease and speed?

Modern amphibious vehicles have several key advantages over earlier models, materials being one. The Amphicar was pure steel, which not only rusts and corrodes but makes it heavy as a rock. To keep a steel craft afloat you need a lot of water displacement, which demands a bulky body that looks odd on the road. Today's amphibious cars and ATVs are built from composite material – a strong and lightweight blend of plastics and fibre. These lighter bodies sit higher in the water and require less speed to break the plane.

Propulsion is another huge obstacle. Earlier motorised amphibious vehicles relied on propellers for thrust. Propeller blades had to be small in order to ride high enough on the road to avoid damage, and small propellers provide less thrust. Modern amphibians have switched to waterjet propulsion systems with no moving parts outside the craft. Waterjets take in water through a hole in the bottom of the hull and use power from the engine to turn a centrifugal pump to build up pressure. The pressurised water is then forced through a nozzle in the rear, providing forward thrust.

The military has always been a great supporter of amphibious vehicles, with landing craft, troop movers and jeeps playing critical strategic roles since World War II. With continued military funding and engineering breakthroughs, we might see a commercially viable amphibious car sooner than you think.

## The statistics

### Quadski

**Crew:** One

**Length:** 3.2 metres

**Width:** 1.6 metres

**Height:** 1.4 metres

**Weight:** 535 kilograms

**Max land speed:**
45 miles per hour

**Max water speed:**
45 miles per hour

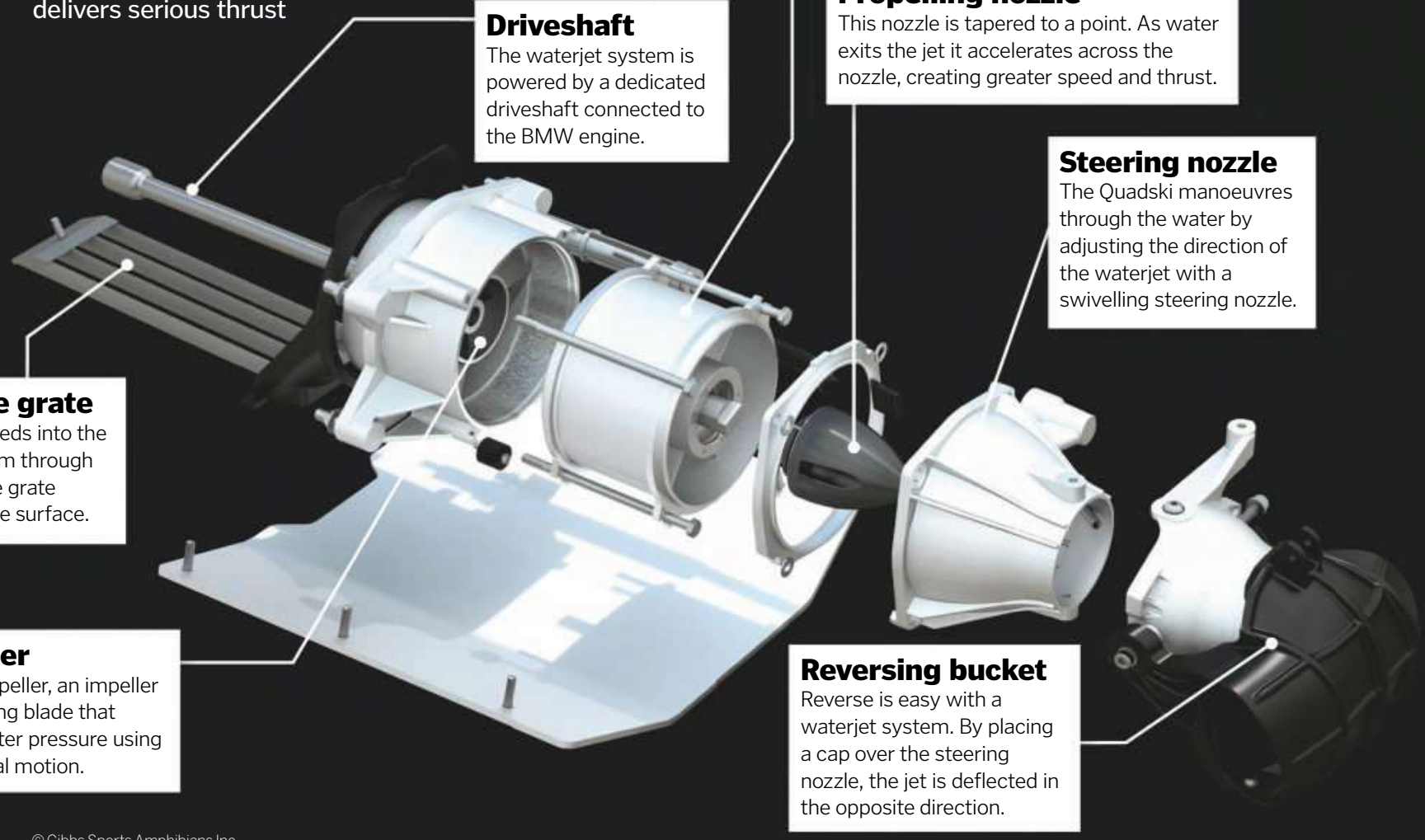
# Gibbs Sports Quadski

## A quad bike that goes from turf to surf in just five seconds

**The Quadski is an amphibious transformer, switching from ATV to jet-ski at the push of a button. The quick-change act centres on the wheels, which fully retract in five seconds thanks to two zippy servomotors. On land, the Quadski looks and rides exactly like a quad bike. For mud-chewing trail rides, the Quadski is powered by the same 130-kilowatt (175-horsepower), 1.3-litre motorcycle engine that supercharges BMW's high-performance racing line. For safety reasons, the engine is capped at 60 kilowatts (80 horsepower) on land, reaching a maximum 45 miles per hour. But the real magic is seeing this lightweight ATV move from land to water. Previous amphibian car concepts were literally dead in the water, slogging slow and low. The Quadski, however, leaps out of the water using the full 130 kilowatts (175 horsepower) to pump water through its jet propulsion system. By riding high on the surface on its fibreglass hull, the Quadski is able to match its maximum land speed out on the water.**

## Jet propulsion up close

The Quadski's compact waterjet system delivers serious thrust



### Driveshaft
The waterjet system is powered by a dedicated driveshaft connected to the BMW engine.

### Pump housing
The closed environment of the pump housing is key to building high water pressure.

### Propelling nozzle
This nozzle is tapered to a point. As water exits the jet it accelerates across the nozzle, creating greater speed and thrust.

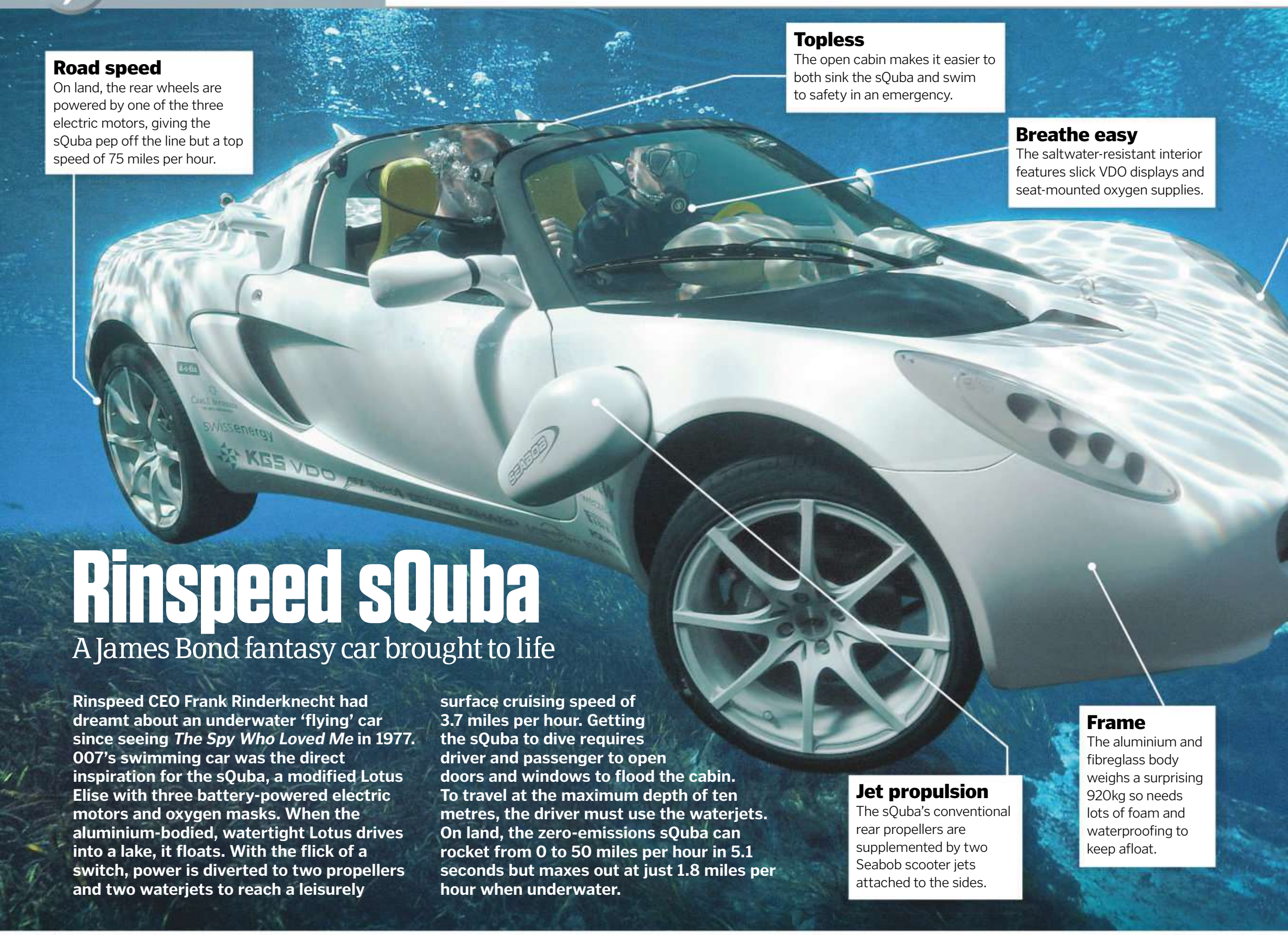
### Steering nozzle
The Quadski manoeuvres through the water by adjusting the direction of the waterjet with a swivelling steering nozzle.

### Intake grate
Water feeds into the jet system through an intake grate below the surface.

### Impeller
Like a propeller, an impeller is a rotating blade that builds water pressure using centrifugal motion.

### Reversing bucket
Reverse is easy with a waterjet system. By placing a cap over the steering nozzle, the jet is deflected in the opposite direction.

© Gibbs Sports Amphibians Inc




**Road speed**
On land, the rear wheels are powered by one of the three electric motors, giving the sQuba pep off the line but a top speed of 75 miles per hour.

**Topless**
The open cabin makes it easier to both sink the sQuba and swim to safety in an emergency.

**Breathe easy**
The saltwater-resistant interior features slick VDO displays and seat-mounted oxygen supplies.

**Jet propulsion**
The sQuba's conventional rear propellers are supplemented by two Seabob scooter jets attached to the sides.

**Frame**
The aluminium and fibreglass body weighs a surprising 920kg so needs lots of foam and waterproofing to keep afloat.

# Rinspeed sQuba

## A James Bond fantasy car brought to life

**Rinspeed CEO Frank Rinderknecht had dreamt about an underwater 'flying' car since seeing *The Spy Who Loved Me* in 1977. 007's swimming car was the direct inspiration for the sQuba, a modified Lotus Elise with three battery-powered electric motors and oxygen masks. When the aluminium-bodied, watertight Lotus drives into a lake, it floats. With the flick of a switch, power is diverted to two propellers and two waterjets to reach a leisurely surface cruising speed of 3.7 miles per hour. Getting the sQuba to dive requires driver and passenger to open doors and windows to flood the cabin. To travel at the maximum depth of ten metres, the driver must use the waterjets. On land, the zero-emissions sQuba can rocket from 0 to 50 miles per hour in 5.1 seconds but maxes out at just 1.8 miles per hour when underwater.**

# Dornier Seastar

## Land, sea and air: this flying boat has got it all covered

A conventional seaplane is nothing more than a Cessna outfitted with floats. Exposed to seawater, metal seaplanes corrode quickly and require constant maintenance in order to keep them airworthy. The hull of the speedboat-looking Dornier Seastar, meanwhile, is made entirely of corrosion-proof composite material.

For terrestrial destinations, the landing gear lowers from the hull. The wide boat hull keeps the craft stable on the water, as does the in-line arrangement of the twin turboprop engines positioned directly over the cabin. The push-pull action of the two propellers can see the Seastar take off – with up to 12 passengers – after just 684 metres and reach a maximum air speed of 180 knots (207 miles per hour). Short takeoffs and landings are aided by two sets of curved sponsons – side projections that add stability to a vessel's hull – located near the middle of the Seastar.

**Boat mode**
The Seastar is a boat that flies – rather than a plane that floats – so it sits low and steady in the water on its V-shaped hull.

**Breaking the plane**
Two sets of sponsons make the hull wider under the wings. The sponsons act almost as hydrofoils to raise the hull when moving.

**Liftoff**
With the nose of the hull out of the water, drag is greatly reduced, so the Seastar can reach takeoff speed in 1,050 metres.

**Gaining altitude**
The push-pull configuration of the twin turboprop engine results in huge thrust, so the Seastar can climb 329 metres per minute.

**Water landing**
The sponsons double up as 'water wings'. As the Seastar touches down, the sponsons create just enough drag to slow it.

### The statistics

***Seastar***

**Crew:** Two
**Wingspan:** 17.7 metres
**Length:** 12.7 metres
**Height:** 4.73 metres
**Empty weight:** 3,800 kilograms
**Max speed:** 207 miles per hour
**Max altitude:** 4,573 metres

### Zero emissions
Rinspeed stripped the Toyota engine from the Lotus Elise and replaced it with three electric motors and six rechargeable lithium-ion batteries.

## The statistics

### sQuba

**Crew:** Two
**Length:** 3.7 metres
**Width:** 1.9 metres
**Height:** 1.1 metres
**Empty weight:** 920 kilograms
**Max land speed:** 75 miles per hour
**Max underwater speed:** 1.8 miles per hour

### Grille gills
When the sQuba floats on the water's surface, the driver can open louvres in the grille to direct water flow toward the rear propellers.

### Turret
The gunner's turret fits one soldier and can rotate a full 360 degrees.

### Smokescreen
The AAV can also fire smoke grenades from two four-tube grenade launchers.

### Battle ready
The rear hatch opens to deploy a battalion of combat-ready Marines.

### Fire power
The turret is armed with a .50-calibre machine gun and 40mm grenade launcher.

### Body armour
The welded aluminium exterior of the AAV is armoured to withstand small arms fire.

### Fast tracks
The all-terrain tracks can manoeuvre through thick sand at up to 45 miles per hour.

# Amphibious Assault Vehicle

## The first to land and the first to fight

**Owned by the US Marine Corps, the Amphibious Assault Vehicle (AAV) is a ship-to-shore troop transporter and fully armed combat vehicle. The AAV weighs close to 30 tonnes and can carry 21 combat-ready Marines and a crew of three.**

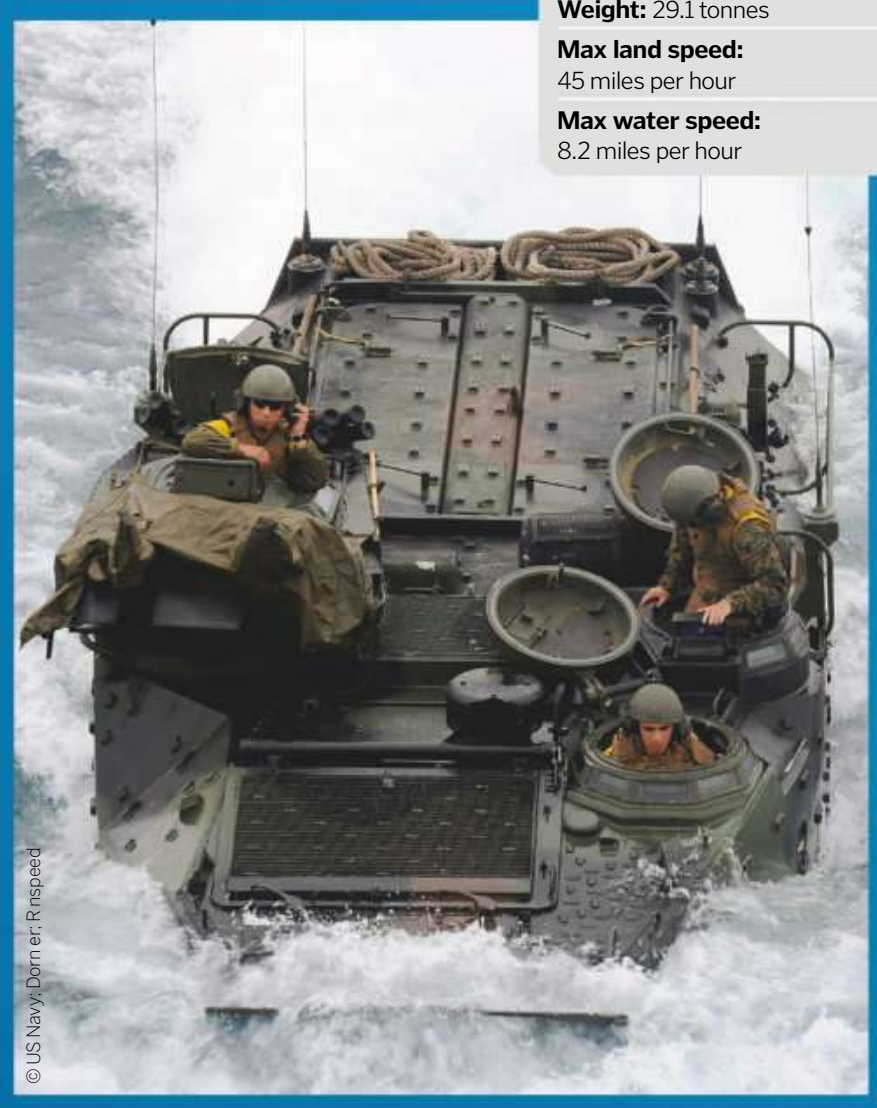
**The amphibious tanks launch from the sea-level well decks of assault ships and roar through the water at about seven knots (8.3 miles per hour) powered by two rear waterjets. The jets are mixed-flow, reversible pumps that propel 52,990 litres of water per minute. In addition to the jets, the AAV gets some propulsion from its spinning tracks.**

**The AAV rides low in the water and can fire its .50-calibre machine gun and 40-millimetre grenade launcher on both land or sea. It makes a seamless transition from ocean to shore and carries enough fuel to haul 4,536 kilograms of cargo as far as 300 miles inland.**

## The statistics

### Amphibious Assault Vehicle

**Crew:** Three
**Length:** 7.9 metres
**Width:** 3.3 metres
**Height:** 3.3 metres
**Weight:** 29.1 tonnes
**Max land speed:** 45 miles per hour
**Max water speed:** 8.2 miles per hour



© US Navy; Dorn er; R rspeed

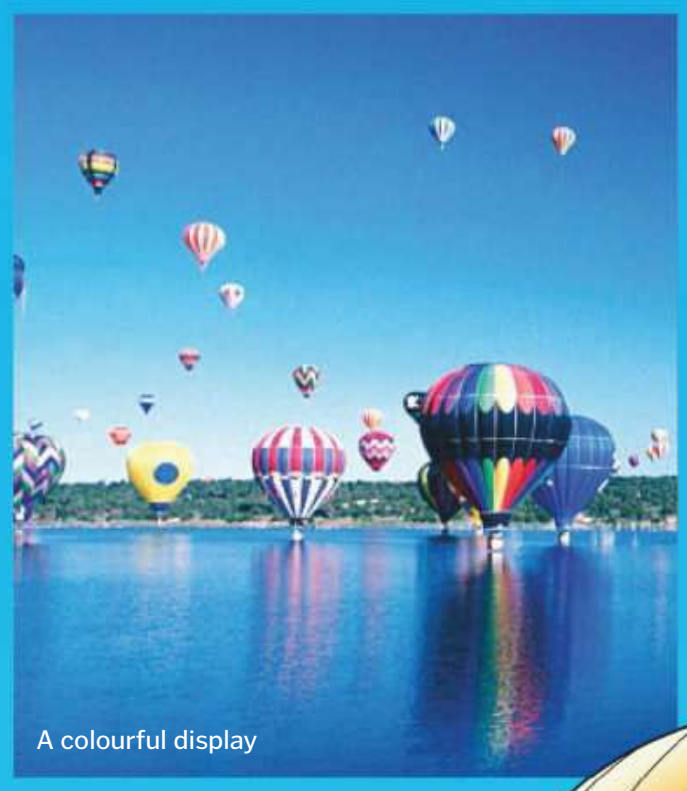
# Hot-air ballo

## How do these gasbags get off the ground and return to Earth safely?

**A hot-air balloon consists of three basic parts: an envelope big enough to displace a large amount of air, burners beneath the envelope to heat the air inside and a basket in which to sit back and enjoy the ride. The scientific principle that enables this lift is convection, or heat transfer.**

**Heating the air inside the envelope causes it to expand, forcing some of the air out of the envelope. The weight of the air inside then decreases, making the balloon lighter and giving it lift. Once the burner is shut off, however, the air inside cools and contracts, causing cold air to rush in from below, weighing the envelope down and causing the balloon to descend. If the burner is powered up intermittently, the balloon can maintain a pretty much constant altitude. Hot-air balloons have an upper limit, because at very high altitudes the air is so thin that the lift is not actually strong enough to raise the balloon.**

**Because hot-air balloons have no real means of changing direction other than upwards and downwards, the vehicle will drift along with the wind. However, a skilled balloonist can manoeuvre horizontally by altering their altitude. Wind is known to blow in different directions at different heights, so the pilot can ascend or descend until they find the appropriate wind to send them in the direction they wish to travel.**



A colourful display

## What goes up...

The envelope is made from ripstop nylon

**Envelope**
Reinforced ripstop nylon fabric – also used for kites, sails and sleeping bags – is the principle material used for hot-air balloon envelopes. This lightweight fabric can also be coated with silicone to make it more hard-wearing.

**1 Inflation**
A balloon crew inflates the envelope using a powerful fan to blow air in from the base of the envelope for several minutes.

**2 Erection**
To get the inflated envelope off the ground, the propane-fuelled burner beneath the envelope is placed at the entrance to the envelope and blasted.

**3 Burner on**
The burner heats the air inside to about 100 degrees Celsius. This causes the air particles to gain energy and move about faster and further apart.

**4 Air expands and rises**
Warm air expands and rises, causing about a quarter of the air to exit through the bottom of the envelope.

**5 Ascent**
The balloon ascends because the air inside the envelope is lighter and less dense than the cold air outside.

# ons

### Parachute vent
If the balloon needs to descend quickly, colder air can enter via a parachute valve or vent in the top of the envelope, controlled by a cord pulled by the pilot.

### Gores
To create the balloon shape from a flat piece of material, it must be cut into long panels from the crown to the base, called gores. These gores are then stitched together to create the shape.

Turning up the heat gets you airborne

### 7 Air contracts
The cooler air contracts, leaving space inside the envelope to suck in more cold air from below.

### 8 Descent
The increased weight of the cooler air inside the balloon exceeds the upthrust. The balloon will start to sink.

### 6 Burner off
Shutting off the burner causes the air to cool down.

### 9 Landing
By gently controlling the burner and descent, the balloon will normally come in to land bouncing along the ground before stopping.

### Propane tanks
Compressed liquid propane is stored in lightweight tanks in the basket.

### Skirt
The flame-resistant material at the base of the envelope is called the skirt. This stops the rest of the envelope from catching fire.

### 10 Landing site
Given the relatively uncontrollable nature of directing a hot-air balloon, the landing site cannot always be predicted, and so the pilot must select a large enough area free from pylons and bodies of water where they can lay out the envelope.

### Burner
Liquid propane flows from the tanks through steel pipes coiled around the burner. When the balloonist triggers the burner, liquid propane flows out and is ignited by a pilot light. In the meantime this flame heats the metal pipes, turning the liquid propane into a gas that is more powerful and fuel-efficient than the liquid when it's cold.

### Basket
Traditionally a hot-air balloon's basket is made of wicker because it's durable, flexible and lightweight. Today hot-air balloons can come with double-decker baskets that seat 50 people if necessary. Enclosed gondolas are also available for serious, long-distance ballooning.

# Airport fire engines

## Not all fire engines are created equal: airport tenders are the heavyweights of the fire-fighting world

We're used to seeing fire engines rush past, sirens blaring, but they're not the biggest, fastest or most powerful fire-fighting vehicles around. If you want to see some serious blaze-tackling hardware, head to your nearest airport. Airport crash tenders are specialised engines that handle some of the most intense and dangerous emergencies in the world – incidents involving aircraft, where planes with hundreds of passengers mix with huge quantities of flammable fuel and oil.

These vast vehicles are kitted out with incredible technology in order to quickly tackle volatile and potentially deadly situations. Flagship airport fire-fighting vehicles are monster 50-tonne machines that can hold 19,000 litres of water and foam, pump liquid at 10,000 litres a minute and accelerate to 50 miles per hour in 25 seconds thanks to dual engines, and they often have six or eight wheels, too. These vehicles include special chemicals to handle jet-fuel fires, and their nozzles are installed on huge, articulated arms that can pierce plane fuselages to get inside the cabin. Firefighters sit inside panoramic cabins with roll cages, control those arms with joysticks and use infrared cameras to navigate dense smoke.

These massive motors don't just have to deal with runway incidents – airports use these vehicles to respond to fires around the airport, which means beefy tyres that can go off-road with ease. And airports don't just use these huge trucks – they have faster first-response vehicles, command trucks to manage major incidents and motorised stairways to get passengers off planes.

Airport fire engines are hardcore bits of hardware, but it's no surprise that they're the most outrageous fire-fighting vehicles in the world – these extreme machines have to deal with extreme situations.

**Maximum reach**
Nozzles are attached to huge, extending and angled arms to help firefighters reach tricky spots – even into plane interiors.

**Nozzle knowledge**
Powerful nozzles pump water and foam across huge distances, and they have piercing technology to get inside plane cabins, too.

**A wider view**
Fire tender cabins have wraparound glass to give drivers and crew better awareness of their surroundings.

**Big wheeler**
The largest airport fire engines have eight wheels with all-wheel drive for maximum acceleration and manoeuvrability.

## Airport fire engines explored

Want to dive inside the world's best fire engines? Here's our in-depth guide

The specialist fire-fighting equipment in Dubai saved lives in 2016

© Shutterstock

## Crash landing in Dubai

**Every airport hopes that its fire engines won't be needed, but when these incredible machines are pushed into action, they can save lives. In August 2016 in Dubai, an Emirates plane experienced difficulties when landing in heavy winds. The crew aborted a landing, tried to have another go, but crashed to the runway again – without the landing gear properly extended. The plane skidded along the runway, an engine detached and several fires started, but fire engines were on the scene within 90 seconds. The fire crew and their advanced equipment undoubtedly saved lives that day – there were 300 people on the plane, and they were all evacuated. It took firefighters 16 hours to bring the fire under control, but sadly one firefighter lost their life after an explosion as flames reached the fuel tank.**

*"Airport crash tenders handle the most intense emergencies in the world"*

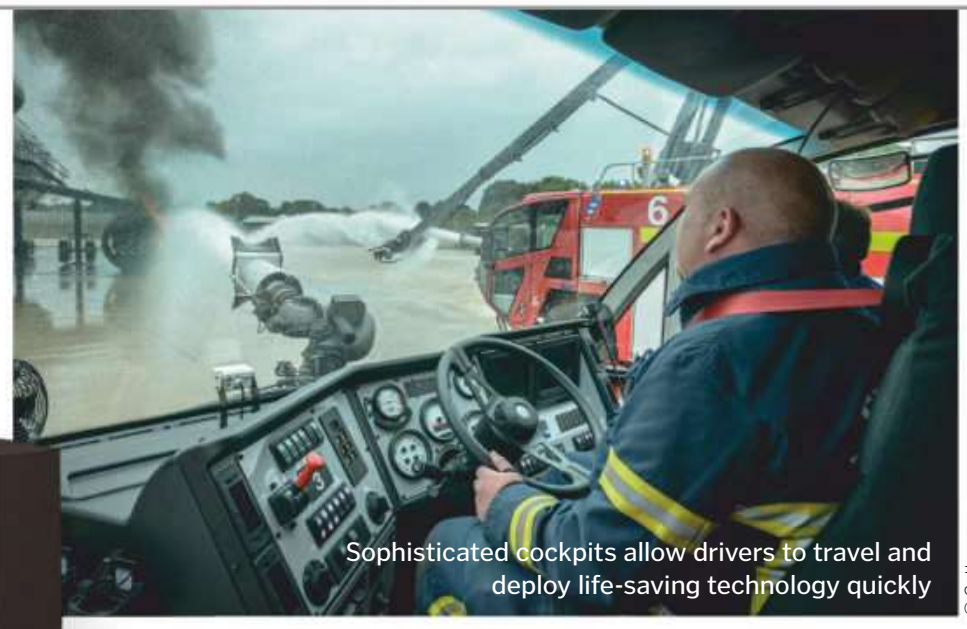
**Locked and loaded**
Airport vehicles are packed with specialist kit so firefighters can tackle every incident - from plane evacuations to conventional car crashes.

**Water tank**
The biggest trucks can hold up to 19,000 litres of water and foam in their vast storage tanks.

**Hardcore horsepower**
Some vehicles weigh more than 50 tonnes, so they often include two engines that produce more than 1,400 brake horsepower.

Huge arms and piercing nozzles allow fire crews to reach tricky spots, like inside planes

**Flame-fighting foam**
These vehicles don't just carry loads of water – they have anti-flame foam and dry compounds to tackle other hazardous materials.



Sophisticated cockpits allow drivers to travel and deploy life-saving technology quickly

© Getty

© Alex Pang



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## 5 FACTS ABOUT THE WORLD'S BEST FIRE ENGINES

**1 In arm's reach**
The biggest airport fire tenders have arms and ladders that are more than 40 metres long so they can reach above the largest passenger and freight aircraft.

**2 Grinding the gears**
Many airport fire engines have gearboxes with a whopping eight gears to give drivers more control over these machines' extreme acceleration in tough and varied environments.

**3 All-round protection**
Many fire-fighting trucks have nozzles that point towards the ground in case the vehicles need to be driven through fires to reach their destination.

**4 Pump up the volume**
The centrifugal pumps in the biggest airport fire tenders can pump water or foam up to 100 metres.

**5 Finding your way**
Airport fire engines have special satellite navigation and camera systems that help drivers navigate around busy airports.

## What next for airport fire engines?

**Airport crash tenders are full of sophisticated equipment, but that's just the start – fire engines will become more reliant on better technology in the future. Fire tenders will become electric, which will make them greener. They'll be smaller and lighter, which will make them quicker and more manoeuvrable, and redesigned suspension systems will allow vehicles to raise or lower when they need to travel over different terrain.**

**Eventually fire engines will include autonomous driving, haptic feedback for better situational awareness and more cameras to allow crews to see their surroundings. They'll even have drones and robots for reaching tricky, hazardous spots – ideal in risky airport environments.**

In the future, fire vehicles will be packed with technology – and they'll be electric, too

© Getty

AR ZONE!

The projected hourly cost to fly a Celera 500L is $328 (around £245)

The interior of the aircraft is built with style and functionality, with a cabin height of around 1.8 metres

## On board the Celera 500L

How this next-gen aircraft flies through the sky

460 MILES PER HOUR SPEED

5,180-MILE RANGE

CAPABLE OF OVER 550 HORSEPOWER

**Wings**
The Celera 500L has a wingspan of over 15 metres, almost as long as the 12-seater Cessna Citation XLS.

**Seating**
In the belly of the aircraft are six first-class seats for passengers.

**Laminar flow**
Laminar flow prevents turbulence during flight, and the Celera 500L is designed to maintain this smooth flow of air over the body and wings of the plane.

# Inside a clean-air plane

## Could this strangely shaped private jet be the future of environmentally-friendly flying?

The Celera 500L may look more like a metal egg with wings than a private jet, but don't be deceived by its appearance. Aircraft like this could be the future of air travel. Created by Otto Aviation, the Celera 500L was dreamt up by the company's founder and former rocket scientist William Otto.

With the intent to design a plane that helps make the aviation industry cheaper and more environmentally friendly, the Celera 500L is proving that both things are possible. Jet-fuelled private planes, such as the Cessna Citation XLS, emit thousands of kilograms of carbon dioxide into the atmosphere. As an example, jet fuel produces 9.57 kilograms of carbon dioxide per gallon (around 4.5 litres) used in flight. In a three-hour flight the XLS burns 210 gallons (around 955 litres) of fuel per hour, releasing around 6,030 kilograms of carbon dioxide. However, without any jet engines to fuel and a powerful piston engine in its place, the Celera 500L boasts up to eight-times less fuel consumption than comparable jets. Its engine is also biodiesel compatible, to further propel Otto Aviation's zero-emissions agenda.

What makes this plane so fuel-efficient is not solely down to the engine, but also its sleek, aerodynamic design. The Celera 500L has been designed to massively reduce the physical effects of drag, an aerodynamic force that fights against

**Air intake**
Vents at the back of the aircraft filter air past the engine and out to the propeller, potentially aiding engine temperature regulation and increasing thrust.

**Propeller**
There is a push propeller at the rear of the aircraft to maintain the laminar flow of the plane.

© Otto Aviation

Due to its long range, there are more than 5,000 airports across the US the Celera 500L could make direct flights between

**Engine**
The Celera 500L is powered by a German-built, liquid-cooled, twin six-cylinder RED A03 V12 engine.

© Illustration by Nicholas Forder

**~13 CUBIC METRE CABIN VOLUME**

**22:1 GLIDE RATIO**

**18 TO 25 MILES PER GALLON (4.5 LITRES)**

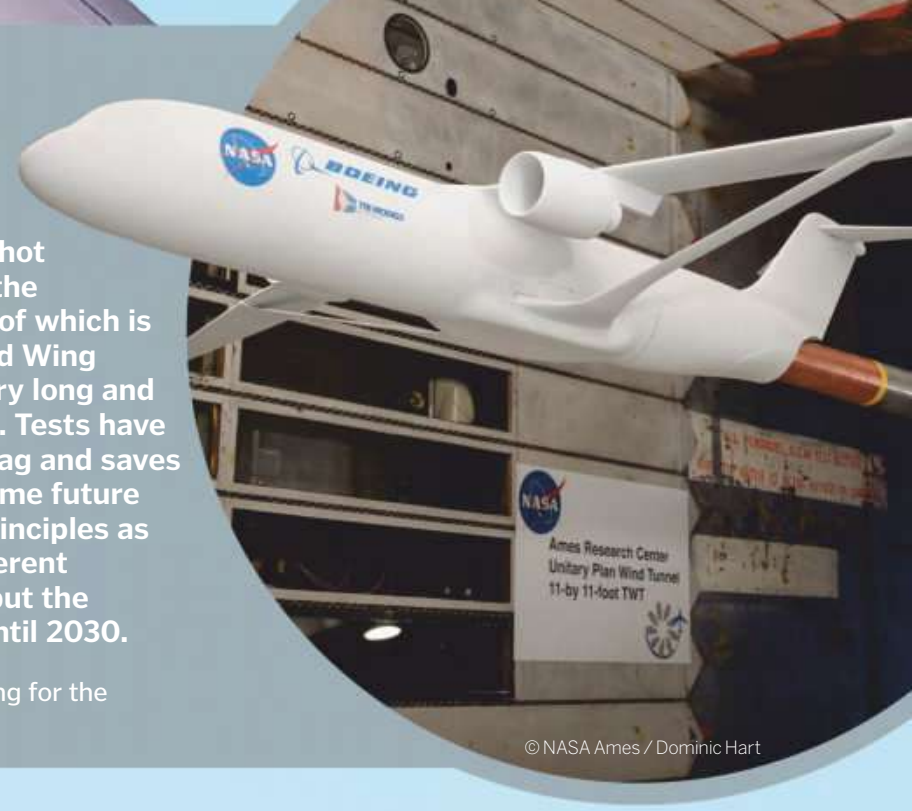
**AR ZONE! SCAN HERE**

the movement of a plane through the air. This is done by making the shape of the plane more streamlined to increase what's known as its laminar flow. The better a plane's laminar flow, the less drag experienced and the less fuel needed to fight against it. So far the Celera 500L has made 31 successful test flights, and Otto Aviation has hopes to move into the next phases of certification over the next three to five years before being commercially produced.

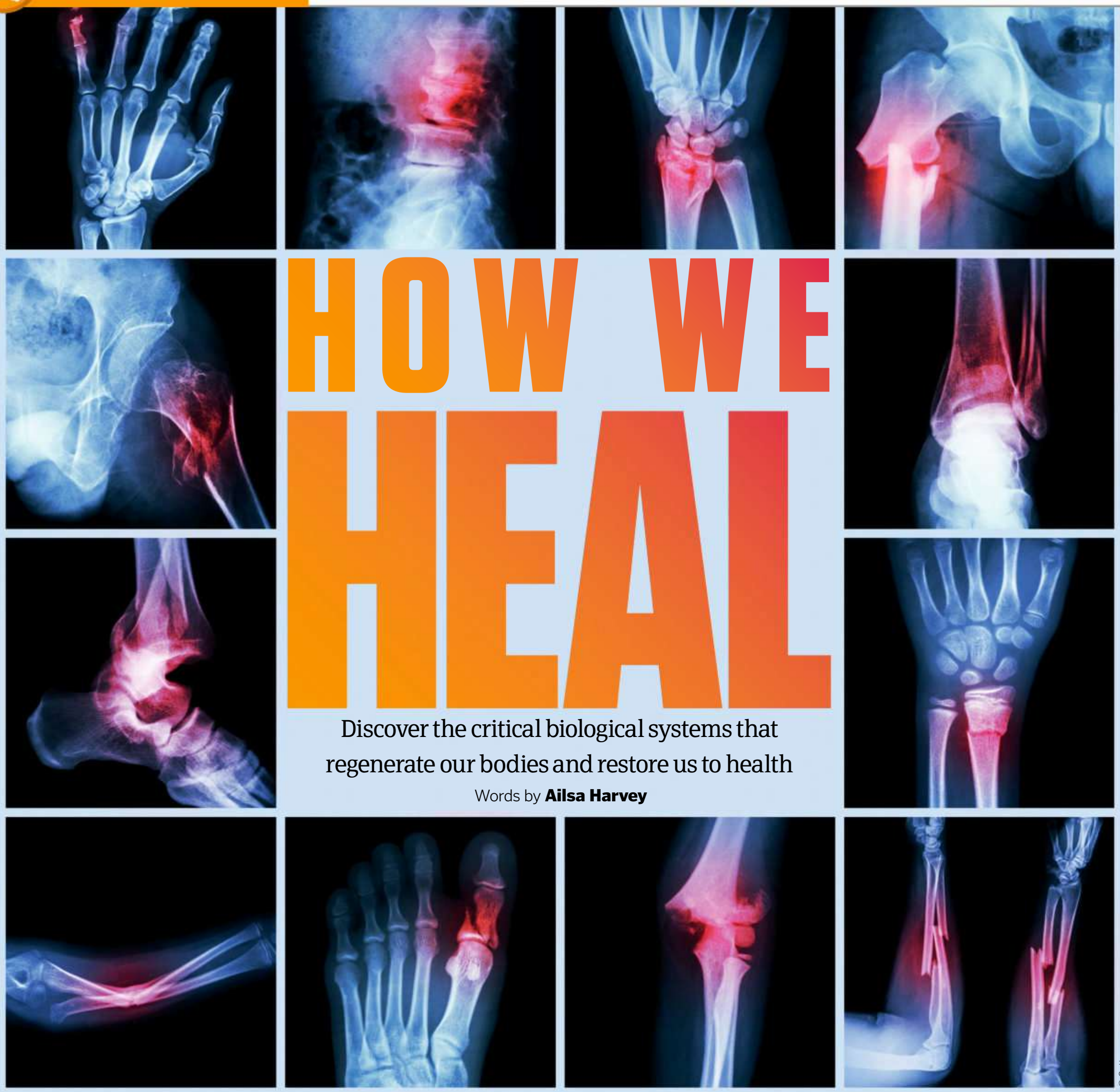
## NASA'S new wings

**The 500L isn't the only plane in development seeking to make the aviation industry more environmentally sustainable. With sustainability being a hot topic right now, NASA is again rising to the challenge with several innovations, one of which is research into the Transonic Truss-Braced Wing (TTBW) concept. These aircraft have very long and thin wings, but need supporting trusses. Tests have shown that this type of wing reduces drag and saves on fuel – as much as nine per cent on some future TTBW plane models – using the same principles as the 500L's design. NASA has tested different versions of the design in wind tunnels, but the technology isn't expected to be ready until 2030.**

An aircraft design developed by NASA and Boeing for the Subsonic Ultra Green Aircraft Research Project




© NASA Ames / Dominic Hart



# HOW WE HEAL

Discover the critical biological systems that regenerate our bodies and restore us to health

Words by **Ailsa Harvey**

© Getty

Every day we use our bodies as tools. Our legs transport us to where we need to be, our fingers can feel and manipulate the objects we hold and our insides work like engines to churn out the energy we need to live. It can be easy to forget about each precise function our bodies provide until one of them fails, becoming fragile or unusable.

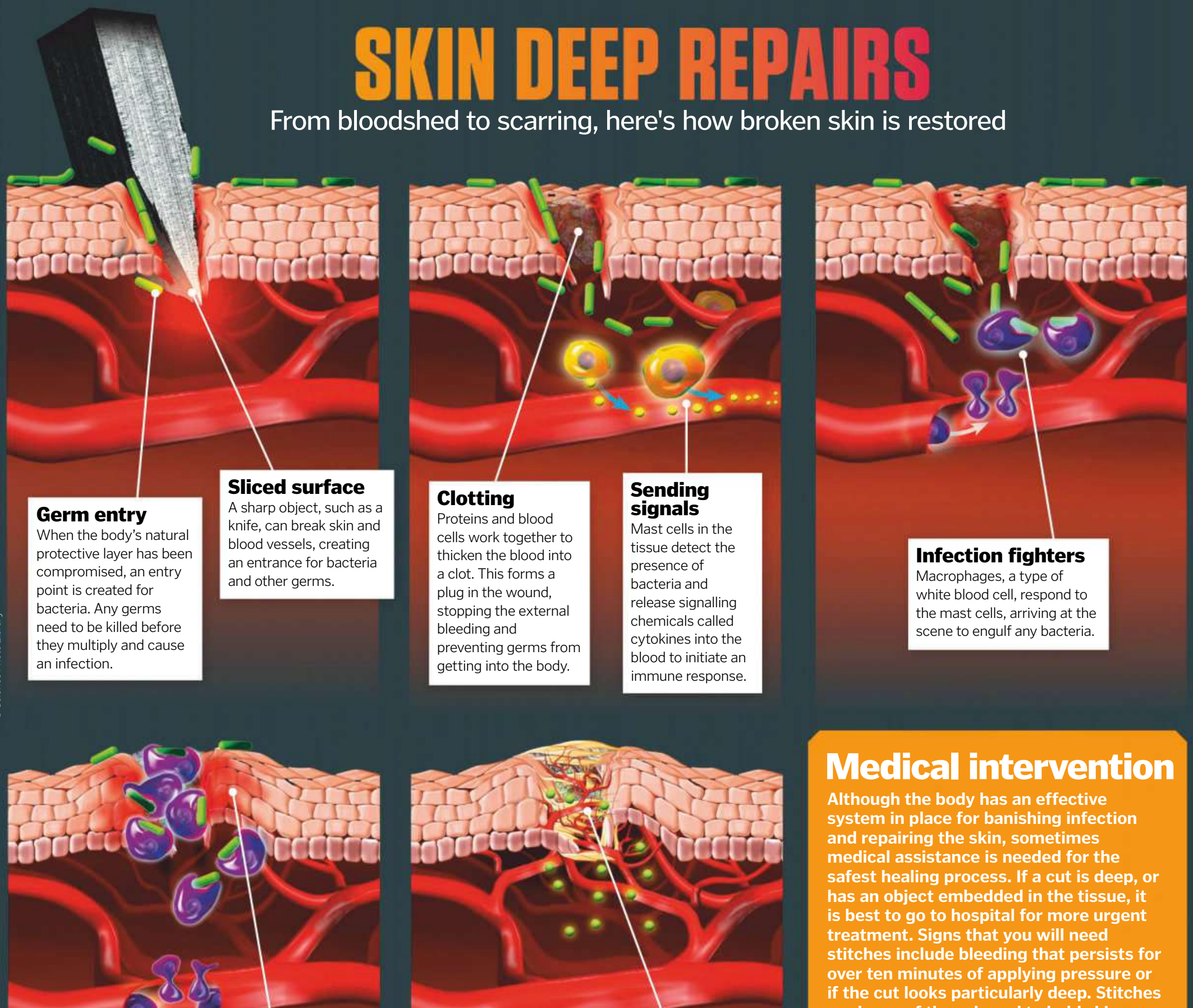
What do we do if a sharp object tears our skin, exposing the flesh and blood that lies beneath our outer protective layers? Thankfully, just as different parts of our bodies are specialised in their unique roles, they have also evolved methods to piece organs back together and restore health from significant sickness. With the constant influx of germs and the quick deterioration that comes with increasing blood loss, we wouldn't last very long without our incredible ability to heal.

When you look in the mirror each day, you may think that the image you are greeted with is fairly constant. But if you were to look at yourself in 28 days time, you would be wearing a completely new skin. The cells that make up your skin are constantly changing – an essential process needed for repairing damage and protecting you. Skin is the largest organ you own. Covering your entire body, it is very exposed to your surroundings, making it the most commonly damaged part of the body. Being able to create new, strengthened skin cells enables your body to close gaps made in this shield, limiting the amount of healing and infection fighting that needs to take place in more vulnerable organs of the body.

Even biological functions that we once thought were fixed have been shown to change. Neuroplasticity is a phenomenon that alters neural signals in the brain. By training the brain, some people have been able to create new pathways, enabling them to improve their memory and even recover from brain damage. As we find new ways to manipulate the most complex areas of human biology, we are expanding the means of reversing damage.

# SKIN DEEP REPAIRS

From bloodshed to scarring, here's how broken skin is restored



### Germ entry
When the body's natural protective layer has been compromised, an entry point is created for bacteria. Any germs need to be killed before they multiply and cause an infection.

### Sliced surface
A sharp object, such as a knife, can break skin and blood vessels, creating an entrance for bacteria and other germs.

### Clotting
Proteins and blood cells work together to thicken the blood into a clot. This forms a plug in the wound, stopping the external bleeding and preventing germs from getting into the body.

### Sending signals
Mast cells in the tissue detect the presence of bacteria and release signalling chemicals called cytokines into the blood to initiate an immune response.

### Infection fighters
Macrophages, a type of white blood cell, respond to the mast cells, arriving at the scene to engulf any bacteria.

### Swelling
The wound becomes swollen, tender and redder as blood vessels widen and blood rushes to the area. This is a result of the immune response. The cut may also weep as clear fluid is produced to clean the wound.

### Rebuilding
New skin is needed to replace the damage. Red blood cells create tough white fibres of collagen. These are the foundations of the new skin tissue, which will be surrounded by granulation tissue, filling in the gaps. As skin grows over this new tissue, the wound is pulled together.

© Science Photo Library

## Medical intervention

**Although the body has an effective system in place for banishing infection and repairing the skin, sometimes medical assistance is needed for the safest healing process. If a cut is deep, or has an object embedded in the tissue, it is best to go to hospital for more urgent treatment. Signs that you will need stitches include bleeding that persists for over ten minutes of applying pressure or if the cut looks particularly deep. Stitches are loops of thread used to hold skin together so that there is less of a gap to fill during the healing process. This makes the healing process speedier, minimising the chance of infection and scarring. Once the skin has healed, hospital staff can remove the thread.**

© Getty

A knot holds stitches in place until they are ready to be removed

© Getty

Bandages can help keep a wound clean

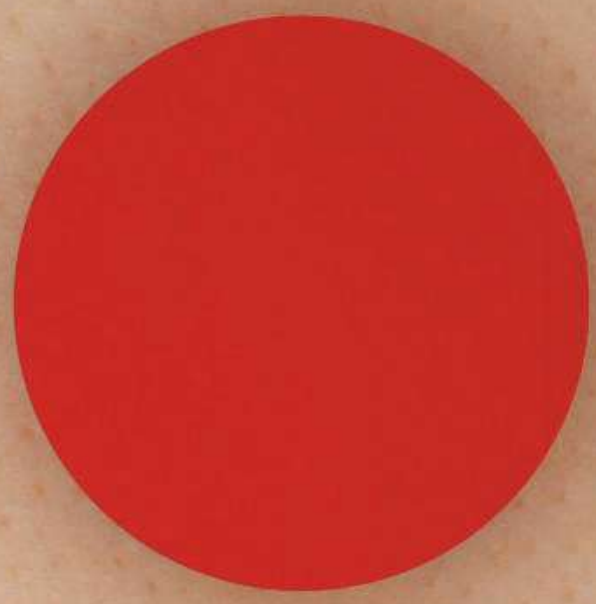
© Getty

Bones aren't as quick to heal as our skin

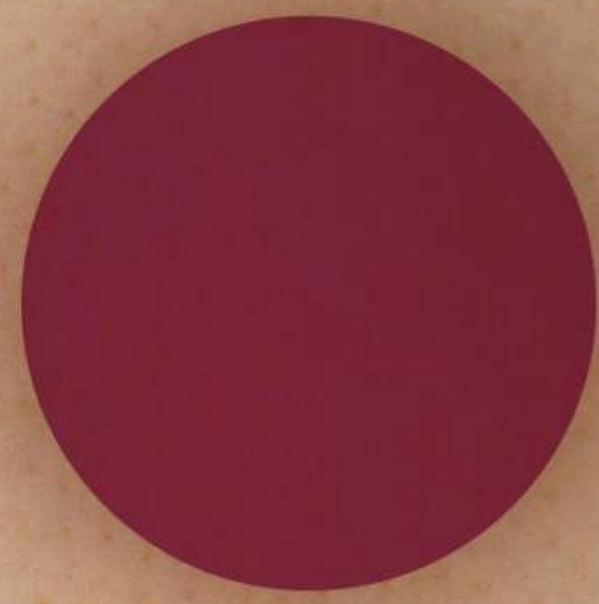
# THE BRUISE SPECTRUM

## What can the colour of your bruise tell you about its healing stage?

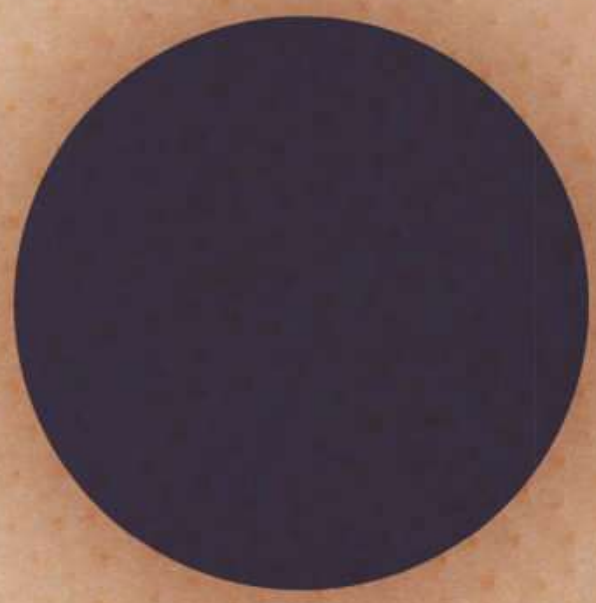
As bruises form and fade, they generally follow a colour pattern. By understanding why these changes occur, you can predict the age of a bruise on your body. The colour of your skin will also change their appearance. Generally, lighter skin tones will display more redness and visible yellow colours, while reddening in darker skin may be less noticeable.



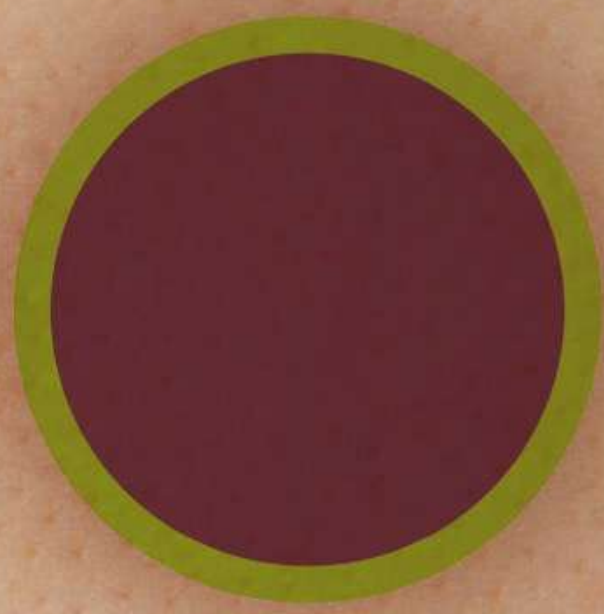
**1 Initial colouring**
Occurring quite soon after an impact, newly leaked blood is bright red in colour, causing red tones to show through the skin.



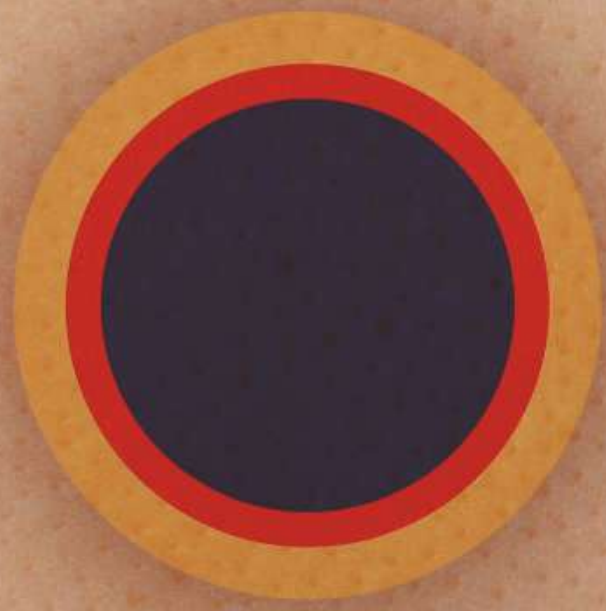
**2 Losing oxygen**
After a few hours, oxygen levels in the leaked blood start to decrease, as it has left the circulatory system. This causes the bruise to darken in shade.



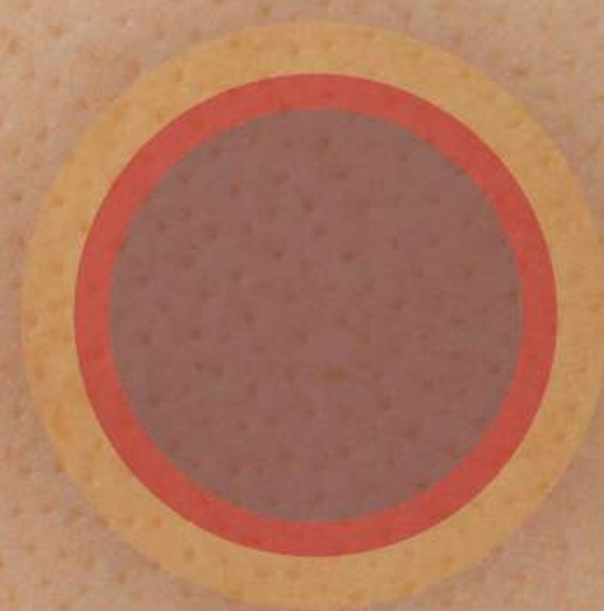
**3 Oxygen depleted**
A day later, the blood has lost all its oxygen. The red cells begin to break down, and iron is released, turning the bruise darker blue, purple or black.



**4 Healing begins**
Shades of green indicate the first stages of healing. The green is caused by the pigment biliverdin, which is produced as haemoglobin is broken down.



**5 Final colouring**
The biliverdin is converted into bilirubin. During this process, the green edges become more yellow.



**6 Fading**
Finally the bruise will begin to fade, becoming brown and lighter as it does so. Most will disappear within two weeks.

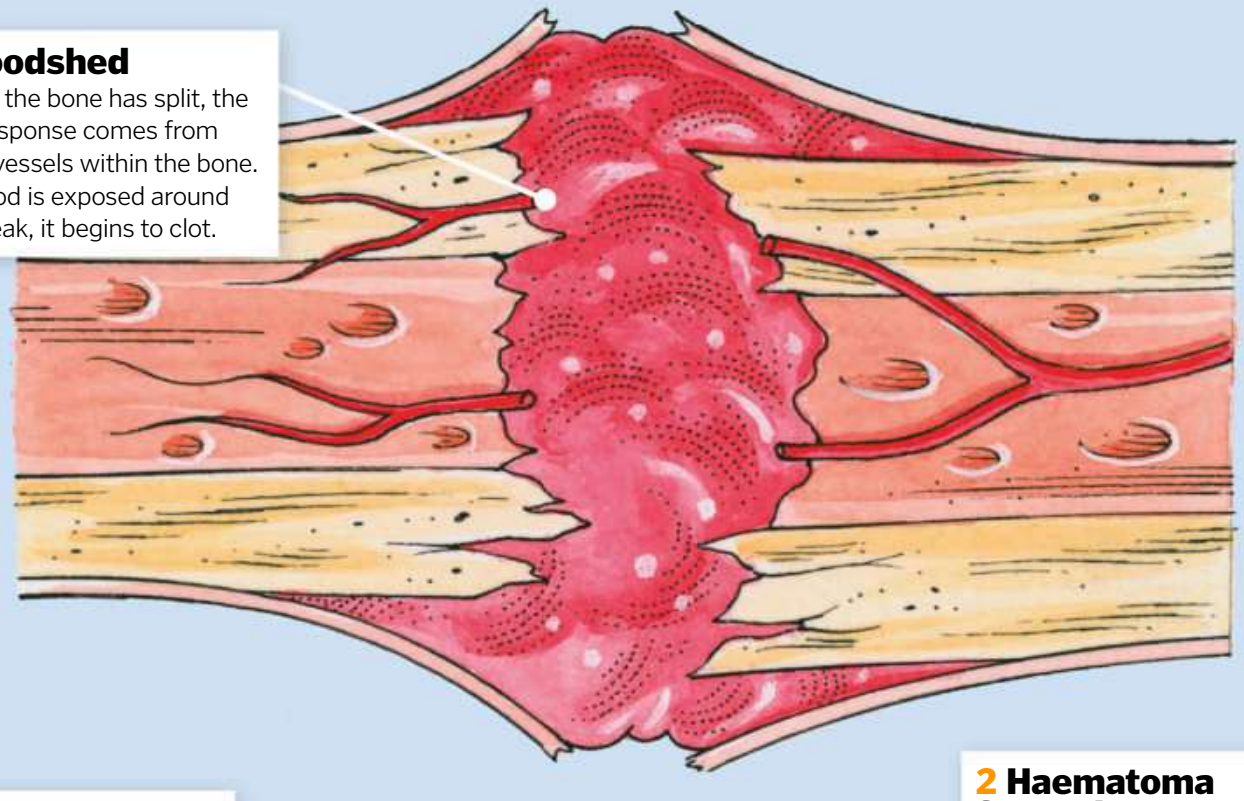
## Battered and bruised

**Blood spills don't necessarily have to be messy. If you class yourself as a clumsy person, the presence of these ever-changing patches on your skin will be a common occurrence. Bruises appear on the skin when the small blood vessels that lie underneath it break. As the blood spreads into the soft tissue, a mixture of blue, purple, red and brown colours can present themselves. Bruises are extremely common; they can be a reminder of that time you missed the gap and fell victim to the corner of a table, or the day you slipped on the rocks.**

**However, some people are more likely to bruise than others, based on the thickness of their skin and the strength of the underlying tissue. If a bruise doesn't disappear after two weeks, or you don't know why you are bruising, it is best to get them checked out by a doctor.**

© Getty

Cooling the area with an ice pack can help to reduce bleeding beneath the skin



**1 Bloodshed**
Where the bone has split, the first response comes from blood vessels within the bone. As blood is exposed around the break, it begins to clot.

**2 Haematoma formation**
This collection of blood is called a haematoma. It quickly acts to fill some of the gap between the two sections of bone.

**3 Swelling**
Tissue around the bone begins to swell. This is a signal from the immune system which attracts stem cells.

**4 Cartilage production**
Soft cartilage is produced to stretch across the gap. This is later replaced by a harder tissue to gain strength.

**5 Complete bone**
Soon the softer tissue will be replaced by a new section of bone. It can take years for the bone to be just as strong as the rest of the skeleton, but it is able to withstand pressure and carry out physical demands.

© Getty

© Getty

An X-ray can show where the fractures in bones are

# REPAIRING BONES

## How does the skeleton fuse together beneath a cast?

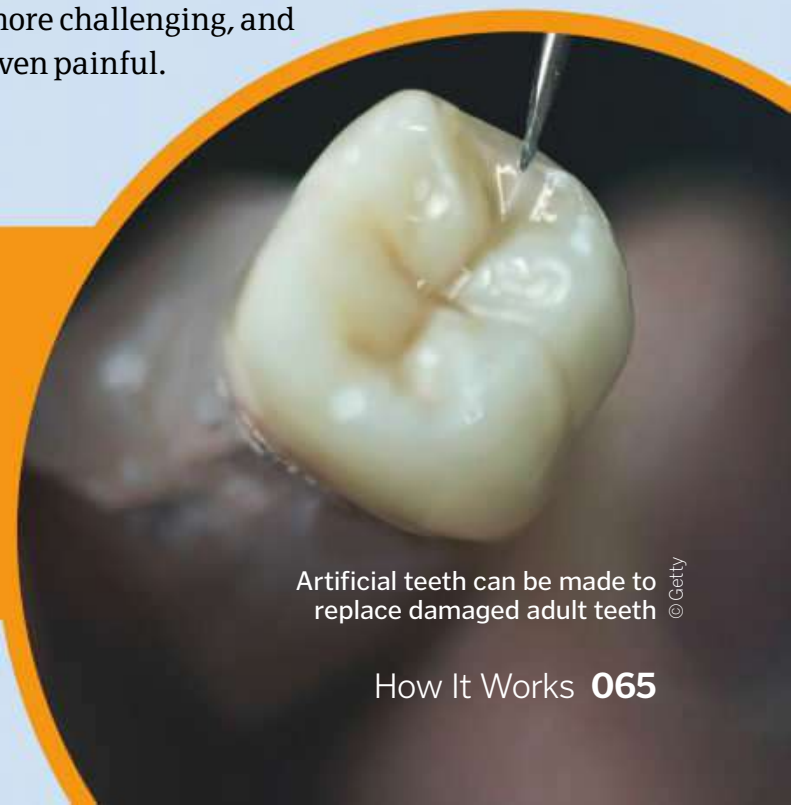
Your bones create a framework to give your body structure. They support you when you move and are designed with the strength to protect our most vulnerable organs. However, not even your bones are invincible, and this becomes all too apparent when you hear a telltale 'crack' after a hard fall.

Broken bones are a relatively common occurrence, and after the early pain, the healing process can seem miraculously straightforward. You might have to get used to having an arm in a sling for a few weeks, or a leg covered in an inflexible concrete-like cast, but once these are removed your bones can return to their roles feeling as good as new.

An essential part of this is positioning. When bones are in the right place, your body is quick to recreate your skeleton's form, but without medical staff to wrap up your limbs and position the pieces, you could end up with your bones reattaching improperly and at the wrong angles. This can make the use of a limb or body part more challenging, and even painful.

## Why teeth don't heal

**Teeth give you two chances to look after them. As a child it doesn't matter so much if you chip a tooth or knock them out. You have a backup set waiting to grow in. Unlike your skin and bones though, these eating tools aren't the best of your body's healers. The enamel covering each tooth is unable to self-repair and is designed to last for the remainder of your life. In order to keep their strong properties, they have hardly any cells or proteins that can promote healing. Instead, 90 per cent of tooth enamel is made of minerals. While dentin – the layer beneath our enamel – is alive and can heal itself, the white outer crown has no living cells and is vulnerable.**

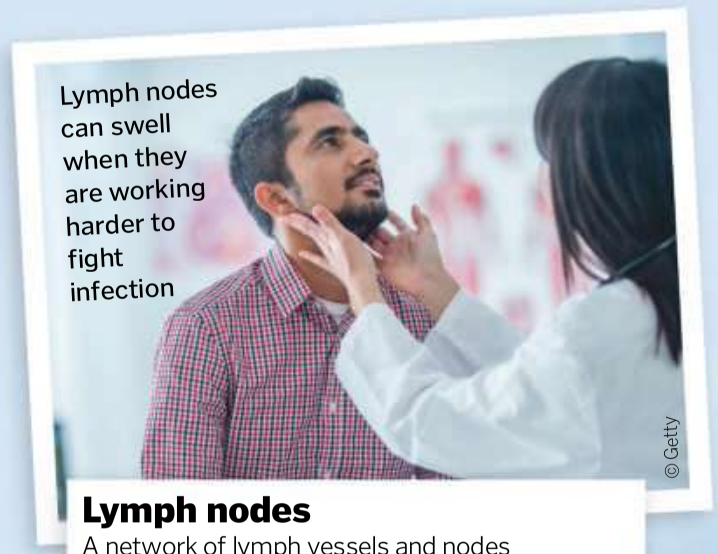


Artificial teeth can be made to replace damaged adult teeth © Getty

# OVERCOMING INFECTION

## Our bodies constantly monitor themselves and are prepared for a fight against invaders

Beyond the closing cuts we can see and the hospital scans that show deeper injuries, our entire bodies are constantly working to remove hidden dangers we may not even be aware of. Whether they're filtering the contents of our bodies before we suffer any symptoms or battling a backlog of microorganisms while we rest, these are the internal instruments that defend and repair us.



Lymph nodes can swell when they are working harder to fight infection

© Getty

### Lymph nodes

A network of lymph vessels and nodes throughout our bodies works as a filtering system to remove toxins in the body's tissues. It flushes out any viruses, bacteria or waste material to reduce the chance of infection. You have hundreds of lymph nodes, constantly receiving contaminated fluid. Equipped with immune cells to fight the invaders, lymph nodes destroy germs carried in through the lymph fluid.

### Thymus gland

Unlike most vital body parts, this gland slowly gets smaller, and is replaced with fat as you age. Before it shrinks, it needs to produce all its life-saving cells before you reach puberty. The cells it makes are T-cells. These help to build an immune response to viral infections by targeting and remembering foreign substances. The thymus gland is also responsible for screening the T-cells produced, killing any that are likely to attack healthy cells. The body's ability to produce an immune response means that when a known infection returns, it can be beaten more quickly.

## 5 FACTS ABOUT HELPING YOUR BODY TO HEAL

**1 Add nutrients to your diet**
Protein is an essential macronutrient used to repair tissue, vitamin C helps the body produce collagen, carbohydrates provide energy for white blood cells and vitamin A controls inflammation.

**2 Get more sleep**
While you are sleeping there are fewer demands made on your heart, and hormones are produced to relax the body and control inflammation. Less energy is being used up by other parts of your body, such as muscles, and more white blood cells are produced as you sleep.

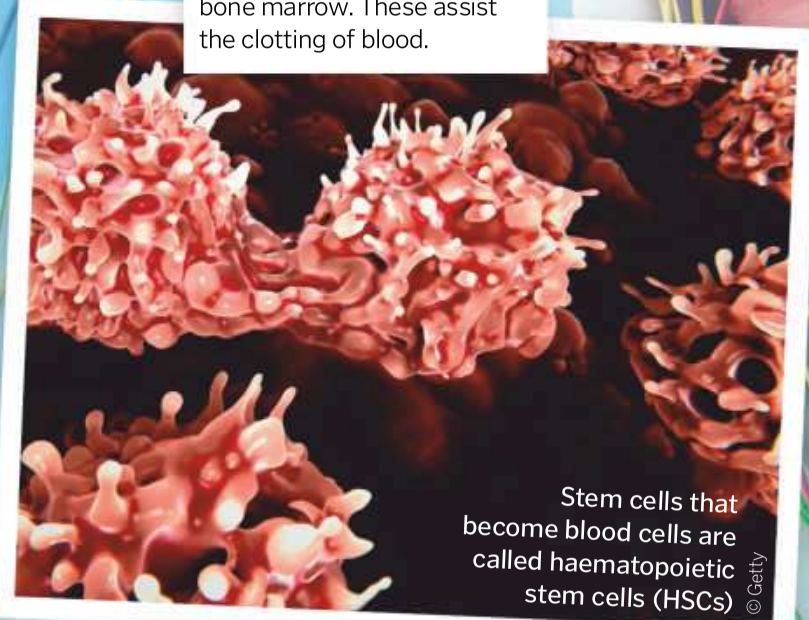
**3 Keep your blood pumping**
Regular exercise can help wounds to heal quicker, but be careful not to drain your energy. Keeping moving helps increase the amount of oxygen that reaches damaged areas as it is transported in your blood. Oxygen is needed by cells as they kill infections, as well as assisting the growth of new tissue.

**4 Stay clean**
Wounds that become infected take longer to heal because your body is working to get rid of the infection before it can restore the tissue. Clean injured skin with antiseptic solution regularly to make the healing process quicker and easier.

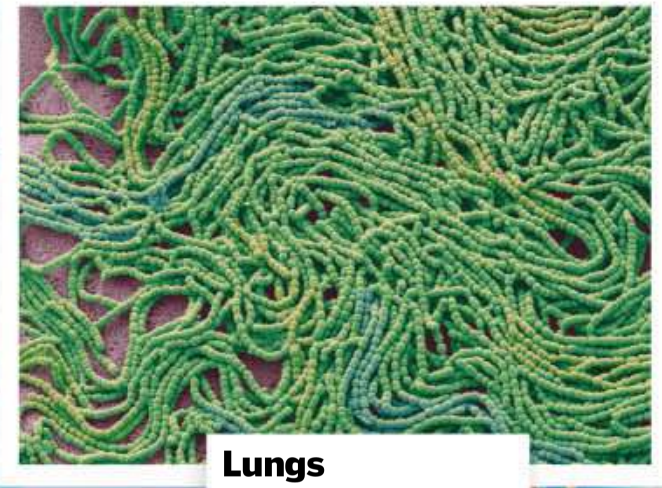
**5 Don't pick your scabs**
Scabs form a layer of protection while the cut heals. They can feel itchy and uncomfortable, but it's important not to touch or pick at them. Picking your scabs increases the risk of infection and slows the healing process. It will also increase the chance of scarring.

## Bone marrow

This spongy substance found at the centre of our bones plays a crucial role in healing both wounds and infection. Constantly producing stem cells, these eventually differentiate to become vital blood cells. Each of the three blood cells made in the bone marrow carries a valuable job for restoring health. The white blood cells patrol the body to fight infections, while red blood cells carry oxygen in the blood, bringing this essential component to the most vulnerable areas. Platelets are also made by the bone marrow. These assist the clotting of blood.



Stem cells that become blood cells are called haematopoietic stem cells (HSCs) © Getty



This scanning electron micrograph shows a close up of mucus that has been produced in the airways © Getty

## Lungs

One easy access point for health-threatening invaders is through the air that we breathe. We need to let the surrounding air in through our lungs in order to provide our bodies with oxygen. But alongside the oxygen there can be germs lingering. Just as your nose does when detecting infectious foreign bodies, the surface of the lungs produces mucus. Tiny hairs in your airways will then sweep the mucus and unwanted germs out of your lungs. If this builds up you may notice that you develop a cough. This assists the movement of the mucus.

## Spleen

This fist-sized organ is found on the left side of your body, near your stomach. Working as your blood's quality control base, it analyses the blood passing through it and makes necessary changes. As blood is pumped through its narrow vessels, it removes any damaged or old red blood cells, breaks them down and returns their material to the bone marrow.

© Getty

**DID YOU KNOW?** *The liver is the only organ in the body that is able to regenerate, fully repairing itself in 30 days*

# THE POWER OF SOAP

## WHEN HUMANITY INVENTED SOAP, IT CHANGED THE WORLD

Words by **Laura Mears**

© Getty

In March 2020, soap sales in the UK more than doubled. This slippery, bubbly substance has a unique chemical make-up that allows it to rip through viruses, disintegrating microbes in milliseconds. It has truly been a lifesaver during the coronavirus pandemic.

Invented in the ancient world, the first soap was just a paste made from fat and ash. People discovered it while trying to remove grease from wool, noticing that mixing burnt wood with water made the process easier. At a microscopic level, alkalis in the ashes were reacting with fats in the grease to create soap molecules. Over time, people refined the soap-making process, learning to boil the fat and ash together to create soap before applying it to their cloth.

By the Middle Ages, soap makers had started to spring up in Europe, where cloth manufacture was big business. They chopped down huge woodlands to make ash and mixed that ash with whatever fat they had available. In the north, this was tallow made from animal fat. Unfortunately, tallow was an essential ingredient for making candles. To keep candle prices low, soap making was taxed, and soap was reserved for cleaning cloth.

*"Soap rips through viruses, disintegrating microbes in milliseconds"*

It wasn't until the 1800s that the cleaning power of soap was properly unleashed. Around that time, illnesses like typhoid and cholera were rife. Most people didn't have easy access to running water, and many believed that washing their skin would cause disease. But this was the century of sanitation, and that was all about to change.

© Getty

Soap has revolutionised healthcare by helping to stop the spread of germs

## How soap is made

**You only need two ingredients to make soap: an alkali, like sodium or potassium hydroxide, and a fat, like tallow or olive oil. The fat supplies molecules called triglycerides, which have a backbone made from glycerol. That glycerol is attached to three fatty acids by bonds called esters. When you mix triglycerides with an alkali and apply heat, the ester bonds snap, releasing the fatty acids from the glycerol. The alkali then neutralises the acids, and this is what forms the soap molecules. Each neutralised molecule has a fatty acid tail at one end, and a charged 'head' at the other. This makes them 'amphiphiles' – a word that literally means 'both love' – describing their ability to dissolve in both fat and water.**

© Getty

Dyes and perfumes turn simple soaps into bath-time treats

## How soap cleans

Clever chemistry allows soap molecules to dissolve in both water and oil

Protective bubble
The heads of the soap molecules dissolve in water, shielding the water-hating grease inside a bubble.
Double-ended soap molecules
Each pin-shaped soap molecule has a head that dissolves in water and a tail that dissolves in fat.
Agitate to lift
As we scrub, the dirt starts to lift away from the surface, and more soap molecules pile in.
Wash away
Trapped grease can no longer stick to the surface, or to other grease, so it just washes away.
Water-hating grease
Stubborn dirt clings to surfaces because it contains fats and proteins that don't like to dissolve in water.
Attack the grease
The tails of the soap molecules are attracted to the fats in everyday dirt, like the oil in spilled food.
CLEAN SKIN

Louis Pasteur proved that germs made people sick, John Snow noticed that cholera outbreaks were spread by dirty water and doctors made the link between hand hygiene and the transmission of infections. As a result, local governments started to install sanitation infrastructure in towns and cities, building sewers, digging drainage and supplying their populations with clean water. And in 1853 the soap tax was finally lifted.

Soap manufacturers started to put effort into making gentler soaps for use on skin, adding perfumes and dyes to make their products more appealing. And people finally started using it to wash their hands and bodies, completely revolutionising personal hygiene.

Soaps aren't just for cleaning; they're added to oils to make machine grease

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Soap lifts stubborn stains from clothes by dissolving grease and grime

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# SOAP

**Soap is the gold standard when it comes to keeping your hands clean. It does more than just kill microscopic bacteria and viruses; it also removes visible dirt and harmful chemicals from the skin. Its grease-lifting action attacks all kinds of everyday grime, from melted chocolate to garden pesticides. But to use it properly you need access to running water, making it a difficult option for people on the move. It's also slightly less effective on viruses that have a protein shell instead of a fatty membrane. These include rhinoviruses, which cause the common cold. Soap can break rhinoviruses down, but hand sanitiser works faster.**

# SANITISER

**Hand sanitiser is soap's portable relative. It contains powerful chemicals – either ethanol or isopropyl alcohol – which, like soap, disrupt the fatty barriers that protect bacteria and viruses. But unlike soap, it also tears through the protein shells that surround rhinoviruses. It does have some disadvantages, however. Hand sanitiser works best on visibly clean hands; it can't get rid of grease, and it becomes less effective at killing viruses when your hands are dirty. For the best results, choose a mixture that contains between 60 and 95 per cent alcohol, and keep rubbing your hands together until they are dry.**

## History of soap

Source: Wiki/ Laurentius

**2800 BCE**
Ancient Sumerians start cleaning wool with mixtures of ashes and fat.

**1550 BCE**
Ancient Egyptians coat their skin with pastes made from oil and soda ash.

**600 BCE**
Ancient Phoenicians make laundry soap using goat tallow and burnt wood.

**100 CE**
A Greek doctor, Galen, notices that soap is good for cleaning the body.

Source: Wiki/Liana

**700 CE**
An Arab chemist, Geber, writes about using soap as a way to keep clean.

Source: Wiki/Knight1817

**1200 CE**
Soap makers start to appear in England, but soap production is heavily taxed.

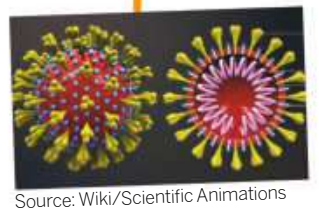
**1600**
Soap is so rare in Europe that most common people have no idea how to use it.

**1853**
The soap tax in England is finally abolished, and washing becomes more common.

Source: Wiki/SpLnd01

**1914**
Oil shortages during World War I drive German scientists to invent the first synthetic detergents.

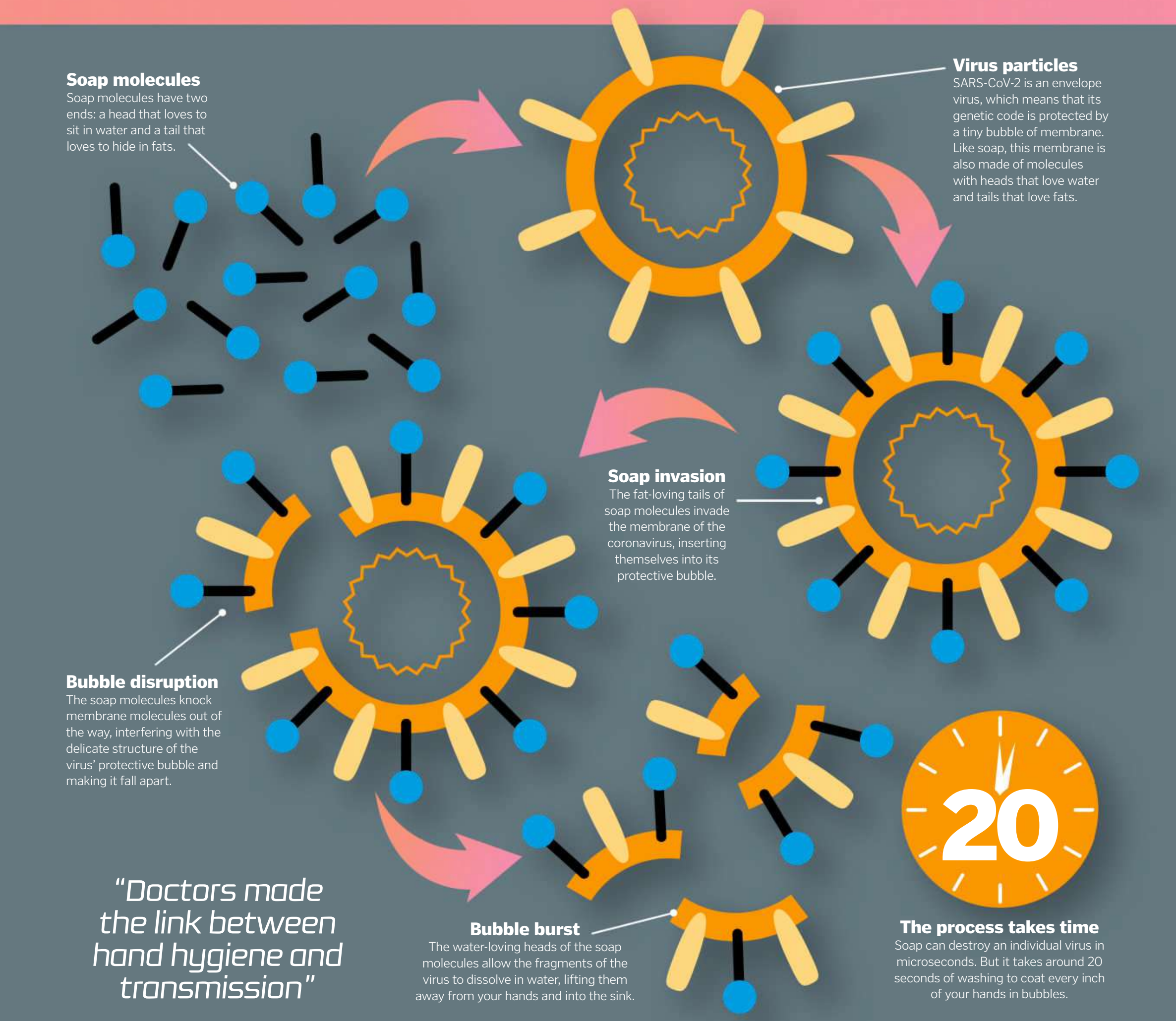
**2019**
Soap becomes humanity's first line of defence against the coronavirus pandemic.



Source: Wiki/Scientific Animations

# HOW SOAP KILLS CORONAVIRUS

## SIMPLE SOAP IS ONE OF THE BEST DEFENCES WE HAVE AGAINST COVID-19


Soap molecules
Soap molecules have two ends: a head that loves to sit in water and a tail that loves to hide in fats.
Virus particles
SARS-CoV-2 is an envelope virus, which means that its genetic code is protected by a tiny bubble of membrane. Like soap, this membrane is also made of molecules with heads that love water and tails that love fats.
Soap invasion
The fat-loving tails of soap molecules invade the membrane of the coronavirus, inserting themselves into its protective bubble.
Bubble disruption
The soap molecules knock membrane molecules out of the way, interfering with the delicate structure of the virus' protective bubble and making it fall apart.
Bubble burst
The water-loving heads of the soap molecules allow the fragments of the virus to dissolve in water, lifting them away from your hands and into the sink.
20
The process takes time
Soap can destroy an individual virus in microseconds. But it takes around 20 seconds of washing to coat every inch of your hands in bubbles.

*"Doctors made the link between hand hygiene and transmission"*

Hundreds of coronavirus vaccines are in development around the world

© Getty

# How the coronavirus vaccine works

## Could a tiny strip of genetic code end the global pandemic?

The immune system is more than capable of suppressing the coronavirus, but first it needs some training. When the virus enters the body, the first thing the immune system needs to do is work out what it is. To do this it sends in foot soldiers, called macrophages, which eat up the remains of infected cells and break them down into pieces called antigens.

The macrophages take these antigens to the nearest lymph node for analysis. There, thousands of immune cells called T cells and B cells pile in to have a look. T cells come in two types: killers, which specialise in killing virus-infected cells, and helpers, which release chemicals to boost the immune response. The B cells are primed to make antibodies, which target virus particles like homing missiles. But there's a catch: there are millions of T and B cells in the body, and each one is slightly different. Only a handful are able to tackle a coronavirus infection. To fight the virus effectively, the immune system needs to find that handful of specialised cells and clone them to make an army. This process takes around seven days, by which time some people are already very sick.

Vaccinations give the body a chance to get this training process out of the way before it encounters the real virus. The new coronavirus vaccines do this by giving the body virus antigen – or the instructions to make it – without any of the rest of the virus. This means that the immune system can find the right T and B cells, and get them ready, without having to worry that the virus is multiplying. The antigen the vaccines focus on is called the 'spike protein', which is the protein the coronavirus uses to get inside human cells. Once the immune system has learnt to target this protein, it can stop the virus in its tracks.

## TOP FIVE VACCINES OF ALL TIME

**1 Smallpox**
This deadly disease was completely eradicated by a vaccination program in 1979. It is the first and only human disease ever eliminated in this way.

**2 Rinderpest**
This cattle plague virus used to wipe out entire herds of cattle and buffalo, causing devastating famines. In 2011 it became the first animal disease ever eradicated by vaccination.

**3 Polio**
Polio is set to be the second human disease eradicated by vaccination. It has almost completely disappeared in most parts of the world, and efforts to totally wipe it out are underway.

**4 MMR**
The triple vaccine against measles, mumps and rubella has saved thousands upon thousands of lives. The measles vaccination alone has saved over 20 million lives between 2000 and 2015.

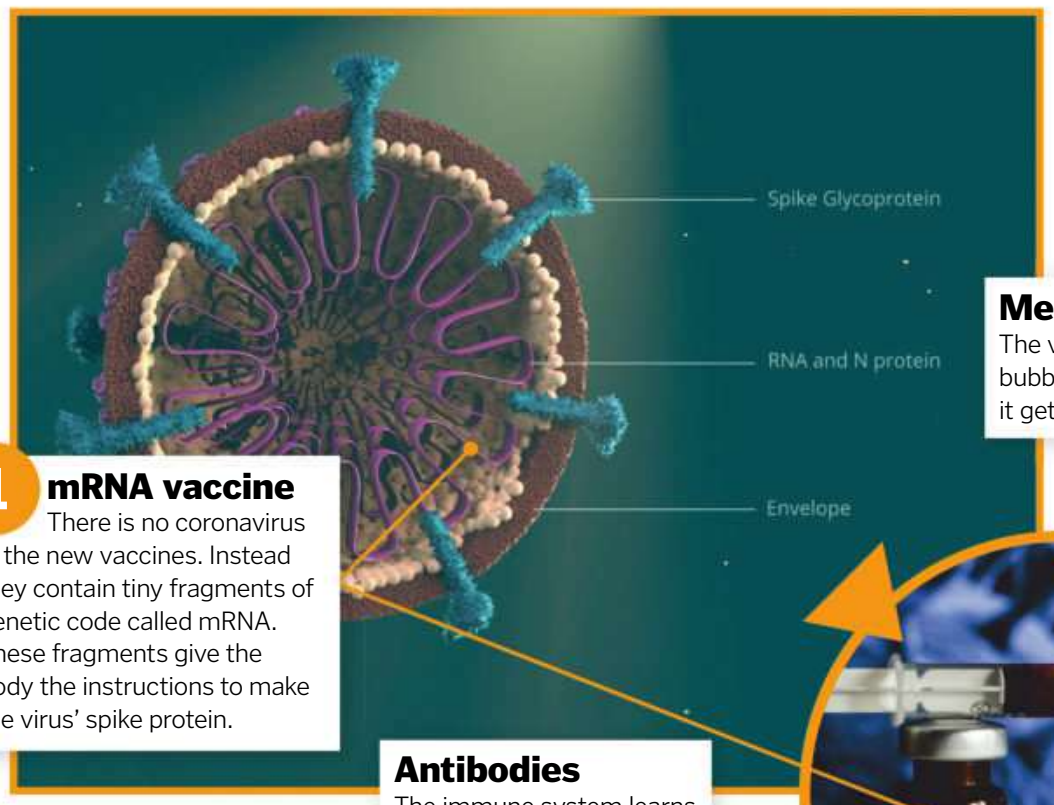
**5 Flu**
The flu vaccine is an annual feat of human ingenuity. With circulating viruses constantly changing, scientists predict the strain we'll need protection from a whole year in advance.

The elderly will be the first to receive a coronavirus vaccination

© Getty

# What is an mRNA vaccine?

Priming the body with viral genetics teaches the immune system how to fight back




**1 mRNA vaccine**
There is no coronavirus in the new vaccines. Instead they contain tiny fragments of genetic code called mRNA. These fragments give the body the instructions to make the virus' spike protein.

**Antibodies**
The immune system learns to make antibodies that stick specifically to the coronavirus spike protein.

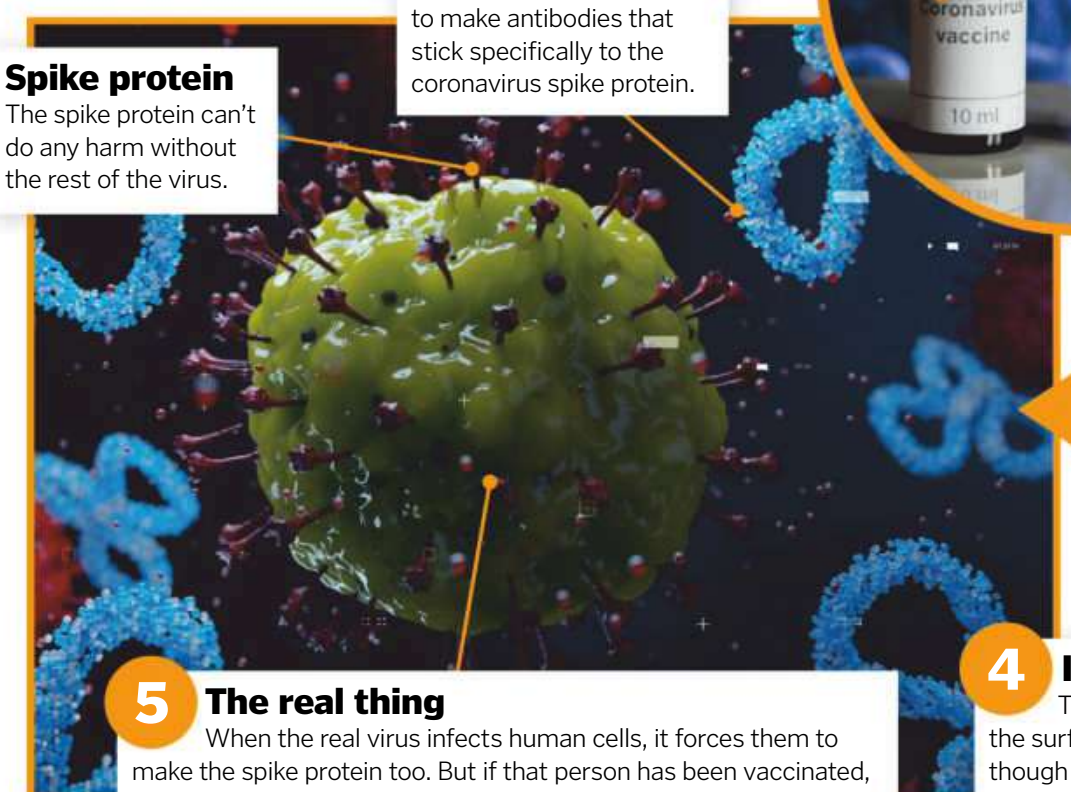
**Membrane**
The vaccine is packaged inside bubbles of membrane to help it get inside human cells.

**2 Injection**
Like many other vaccinations, the coronavirus vaccine enters the body via an injection into the muscle in the upper arm.

**3 Antigen manufacture**
The vaccine enters cells in the arm, delivering the mRNA. The cells then read the coded instructions and start making coronavirus spike proteins. They put the finished proteins on their surface for the immune system to see.

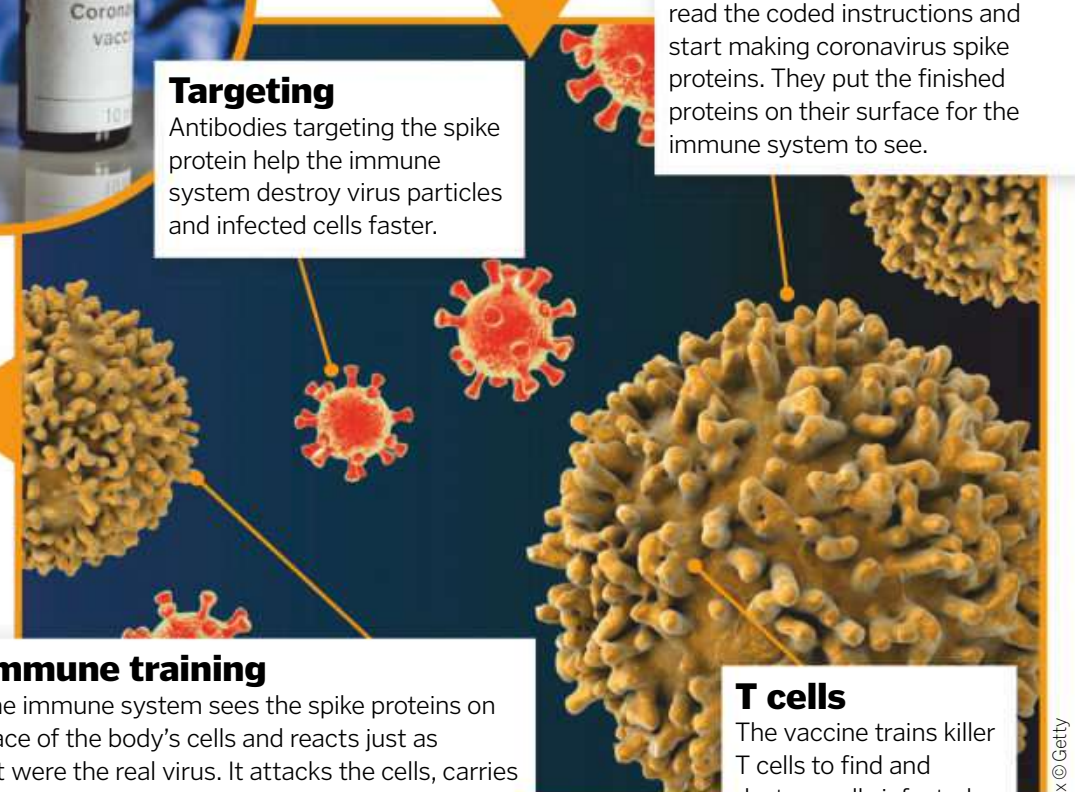
**Spike protein**
The spike protein can't do any harm without the rest of the virus.

**Targeting**
Antibodies targeting the spike protein help the immune system destroy virus particles and infected cells faster.



**5 The real thing**
When the real virus infects human cells, it forces them to make the spike protein too. But if that person has been vaccinated, their immune system will recognise the antigen straight away and start attacking the virus before the person gets sick.

**4 Immune training**
The immune system sees the spike proteins on the surface of the body's cells and reacts just as though it were the real virus. It attacks the cells, carries fragments of the spike protein to the lymph nodes and starts training an army to recognise the virus.



**T cells**
The vaccine trains killer T cells to find and destroy cells infected with the coronavirus.

4x © Getty

## What is herd immunity?

If enough people have immunity, the virus will stop spreading

© Getty

**A virus can only transmit from one person to the next if the immune system of the uninfected person doesn't know how to fight it. As soon as the immune system learns to attack the virus, the chain of transmission stops. The more people who have a vaccination, the harder the virus finds it to infect a new host. 'Herd immunity' is the point at which so many people are immune to the virus that it can't find anyone new to infect. Once this point is reached, transmission all but stops.**

**The great thing about herd immunity is that not everyone needs to be immune to the virus for the whole population to be protected. If most people have a vaccination, it makes it harder for the virus to find the remaining unvaccinated people. This means that people who aren't able to have a vaccination for medical reasons can still be protected.**

The next challenge is to work out how to distribute the vaccinations around the world

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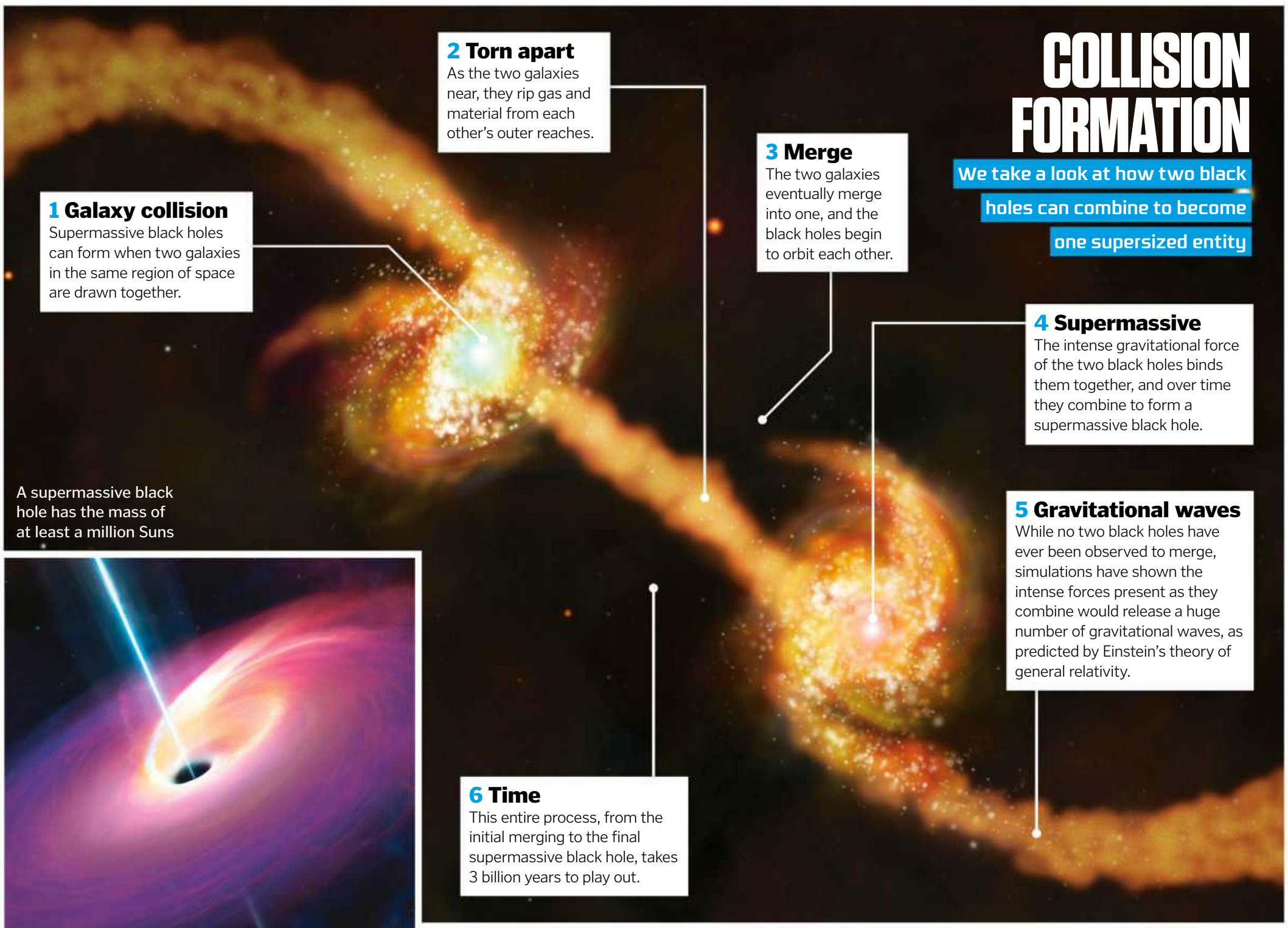
# SUPERMASSIVE BLACK HOLES

**Once thought impossible by scientists, supermassive black holes are now believed to be the heart and soul of every galaxy, powering trillions of stars while spanning an area no bigger than our Solar System**


COLLISION FORMATION
We take a look at how two black holes can combine to become one supersized entity
1 Galaxy collision
Supermassive black holes can form when two galaxies in the same region of space are drawn together.
2 Torn apart
As the two galaxies near, they rip gas and material from each other's outer reaches.
3 Merge
The two galaxies eventually merge into one, and the black holes begin to orbit each other.
4 Supermassive
The intense gravitational force of the two black holes binds them together, and over time they combine to form a supermassive black hole.
5 Gravitational waves
While no two black holes have ever been observed to merge, simulations have shown the intense forces present as they combine would release a huge number of gravitational waves, as predicted by Einstein's theory of general relativity.
6 Time
This entire process, from the initial merging to the final supermassive black hole, takes 3 billion years to play out.
© NASA

A supermassive black hole has the mass of at least a million Suns

© NASA

When black holes were first theorised, many scientists thought their existence was a physical impossibility. How could an object exist from which nothing, not even light, could escape? And how could this phenomenon be large enough to power a galaxy? To this day, many questions remain unanswered about these statistical nightmares, but there's little doubt now that they're real. But just how extraordinary are they?

As you might have guessed, a supermassive black hole (SMBH) contains a lot of mass, roughly equivalent to between a million and tens of billions of Suns. While regular black holes can be found propagating the universe as a whole, often left as remnants of a star going supernova, SMBHs are much less common, but exceedingly more powerful.

To date, every SMBH that has been discovered is located at the centre of a galaxy, indicating that this fascinating phenomenon is not only responsible for giving birth to and maintaining galaxies, but also destroying them. It is strongly believed that an SMBH lurks at the heart of nearly every galaxy, heating the stars and material in its vicinity in addition to recycling matter for the formation of new planets, stars and, in extreme cases, entirely new galaxies. Indeed, at the centre of our own Milky Way, 26,000 light years from Earth, resides the SMBH known as Sagittarius A*.

The realisation that supermassive black holes could be the power sources for galaxies got scientists wondering just how large these things could really become. In August 2019 astronomers announced they had discovered a truly gargantuan black hole. Located in Holmberg 15A, a galaxy around 700 million light years from Earth and part of the galaxy cluster known as Abell 85, this SMBH contains the mass of 40 billion Suns. And this isn't even the biggest detected so far. Although the only measurements made have been indirect, the biggest known is a quasar called TON 618, with a mass of 66 billion Suns.

The reason these black holes can grow quite so big is due to the extreme conditions in which they are formed, with two primary methods currently favoured. The collision theory states that two or more colliding black holes can become gravitationally bound to create an SMBH, while quasar theory suggests newly forming galaxies will eventually pump so much matter into a regularly sized black hole that it will expand to a humongous size over a long enough period.

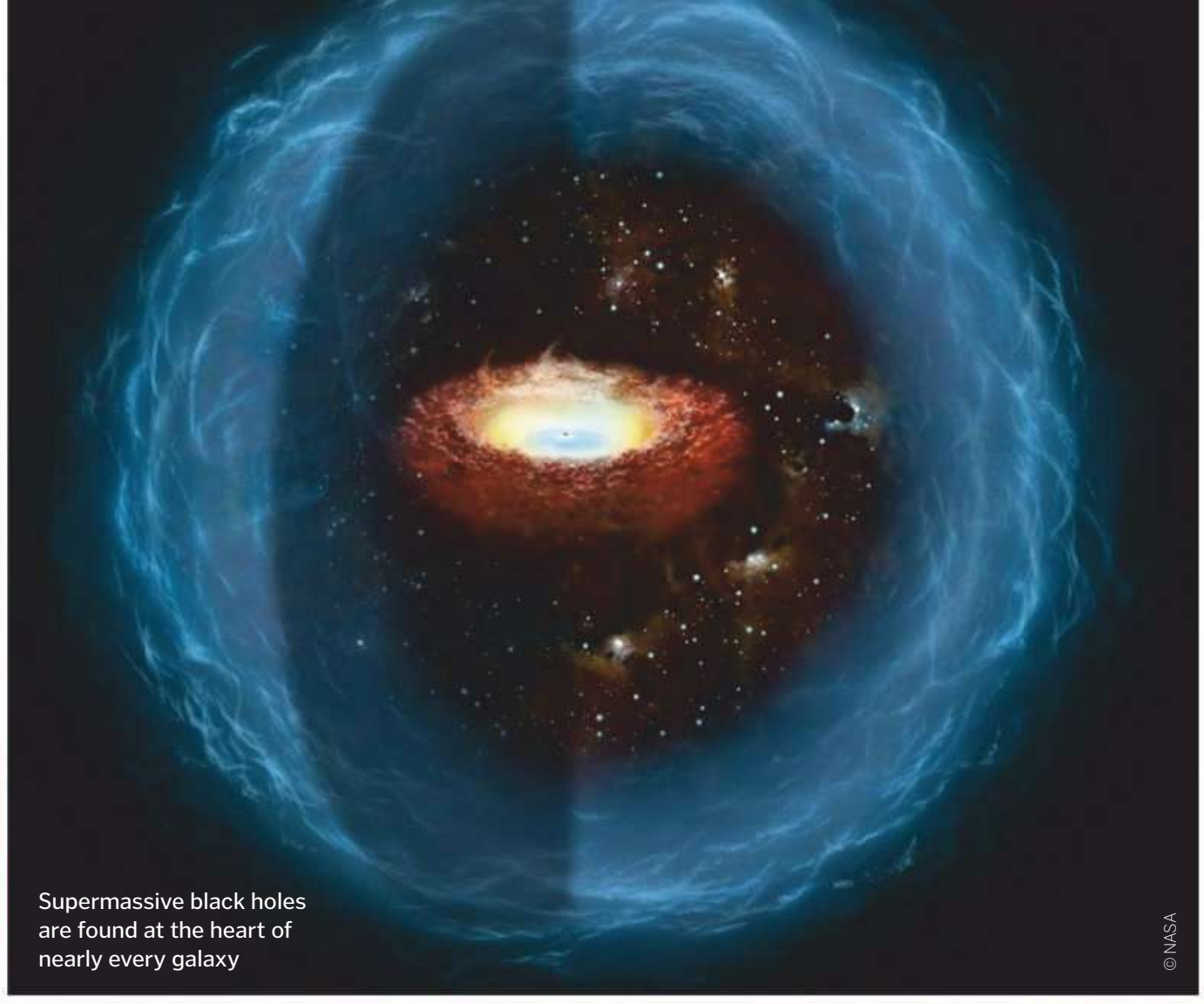
Quasars are the expanses of matter surrounding a black hole and are regarded as the brightest objects in the universe. As a black hole pulls matter in, it swirls around it in a quasar stretching thousands of light years across.

At the very centre of each supermassive black hole is a phenomenon known as a singularity. This might be impossible to believe, but a singularity is no bigger than the full stop at the end of this sentence, but contains more mass than a billion Suns. In fact, the exact physics of a singularity are nigh-on impossible to comprehend, and scientists continue to be baffled by these statistically impossible condensations of matter. Theoretically they contain the majority of the black hole's mass, and thus are infinitely dense, but their

existence is difficult to prove, and so they remain highly controversial.

The gravitational pull that this singularity – and ultimately the entire black hole – exerts is huge, to say the least. As mentioned previously, nothing can escape from a black hole, not even light itself. However, all hope is not lost if you stray too close. The extent to which a supermassive black hole's gravity is inescapable extends outwards several million kilometres to an area known as the event horizon. This is the point of no return, where once matter – and light – passes, it will no longer be able to get away. Surrounding the event horizon is the quasar. Depending on its age, however, something rather odd happens inside the event horizon of a supermassive black hole.

While black holes can consume a huge amount of energy and material, they cannot eat an infinite amount. Once it has reached its limit, it can no longer store matter, instead firing material out vertically – in both directions – as giant jets of energy. These jets can be 20,000 light years across, sending huge amounts of energy into the universe, mostly as X-rays. It is via these jets that the majority of supermassive black holes have been found, as most galaxies can be observed to fire out these blasts of energy. However, as a galaxy ages, the SMBH will accrete less and less matter, eventually becoming almost stable as the remaining nearby material orbits the event horizon inside the quasar. At this point the jets will cease firing.



Supermassive black holes are found at the heart of nearly every galaxy

© NASA

SMBHs have been around since the start of the universe, forming not only through the two methods we look at here, but also through the combination of smaller and smaller black holes. At the dawn of the universe, roughly 14 billion years ago, large clouds of dust and gas drifted free. However, as proven by experiments at giant particle accelerators, such as those at CERN, the collisions between atoms produced mini black holes. Over time these would be pulled together by gravity into larger regular-sized black holes. After hundreds of millions of years, supermassive black holes were created at the centre of these dust and gas clouds, in turn spurring the creation of new stars and subsequently entire galaxies.

These ancient but almost everlasting power generators might be terrifying to imagine, but there's little doubt that they're integral to both the formation and general upkeep of galaxies. It's unlikely we'll ever visit one ourselves, but from afar we can observe these cosmological wonders in the detail necessary to appreciate the job they do to keep the universe ticking over.

## Galaxy killer

### Can a supermassive black hole take down a galaxy?

**Not all supermassive black holes can destroy a galaxy. After all, there's one at the centre of the Milky Way and we're still standing. However, supermassive black holes can destroy a galaxy in some instances if the necessary material for stellar formation is accreted, or gathered, by the SMBH. The X-ray emissions of every supermassive black hole far exceed that of all other sources of X-rays in the universe put together, while the energy swirling around the SMBHs present in just one-third of galaxies in the universe is enough to tear apart every massive galaxy in the universe 25 times over. This huge outpouring of energy can, in some cases, expel the dust and gas present in a galaxy that is required to generate new stars. As the older stars in such a galaxy die out, no newer ones are produced – once the black hole has consumed all of the available material, the galaxy would cease to exist.**

**Destruction**
Stars in a galaxy can be torn apart by a black hole.

**Pulling power**
Black holes will suck in any material and radiation in their immediate vicinity.

**Thief**
A black hole can destroy a galaxy by 'eating' the material necessary for stellar formation.

© NASA

# QUASAR FORMATION

**Black holes are formed when a young galaxy reaches maturity. But how does this work in practice?**

**1 Matter**
In a young galaxy, matter continually falls into a regularly sized black hole.

**2 Quasar**
Eventually the material heats up and no more can be taken in, forming a super-hot quasar around the black hole.

**3 Jets**
When the black hole can take in no more matter, it blasts it out into space in the form of huge jets of energy.

**4 Bright**
Quasars are composed of scorchingly hot material and are the brightest objects in the universe. Only young galaxies have quasars.

**5 Push and pull**
In very basic terms, a black hole pulls gas in, while a quasar forces it out.

**6 Supermassive**
Once there is no more material left to be fired out in jets, a supermassive black hole remains at the centre.

The bright light at the centre of galaxies indicates the presence of SMBHs

© NASA

Any star straying within the vicinity of a black hole will likely be torn apart

© ESO

© NASA

# BLACK HOLE TIME TRAVEL

**Could a supermassive black hole be used to travel forward in time? Stephen Hawking certainly thought so. He suggested that if a spaceship orbited a black hole 24 million kilometres in diameter beyond the distance at which it would be pulled in – approximately a further 24 million kilometres – time would slow down for the crew on board. One full orbit would take the spaceship 16 minutes according to observers watching from Earth, but for the crew each orbit would only take eight minutes. If they did this for ten full Earth years, when they returned home, 20 years would have passed.**

**Hawking put this down to the interaction with space and time, as the gravitational pull of a SMBH affects space-time and alters conditions for those in its vicinity.**

AR ZONE!

# WEIRD MOONS

## Meet some of the strangest natural satellites in the Solar System

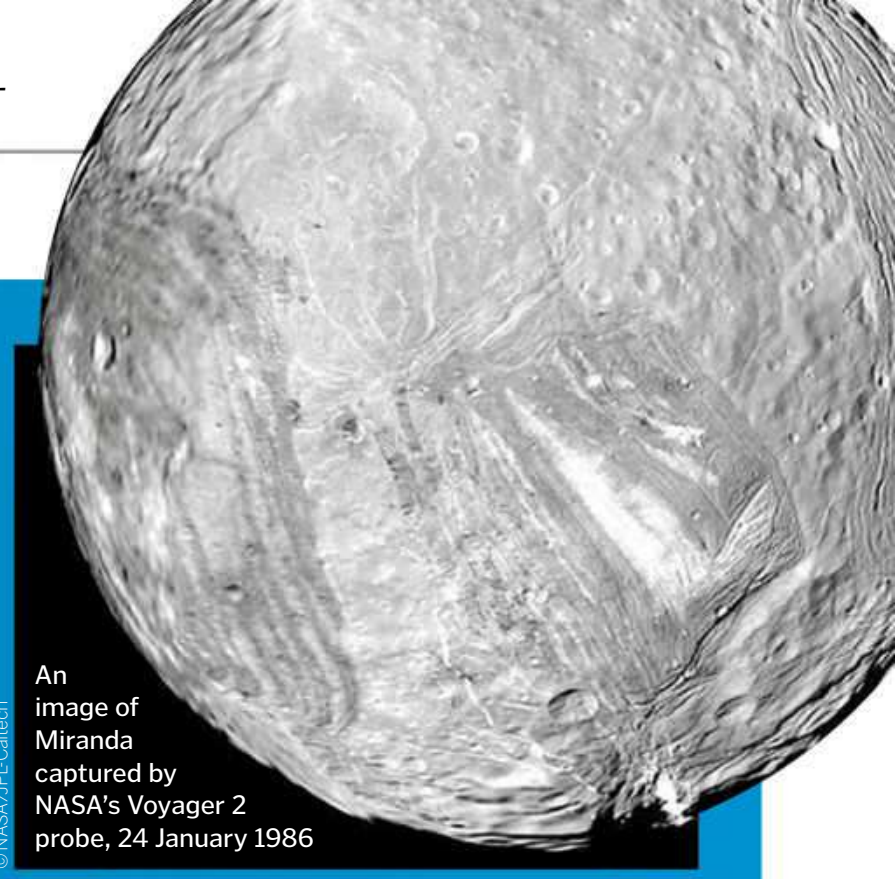
Words by **Scott Dutfield**

# Frankenstein formation

Name Miranda Planet Uranus
Size 27x smaller than Earth Discovered 1948

**On the surface Miranda looks like a patchwork moon. However, its lunar looks are the result of hundreds of miles of rocky ridges. There are three giant features called coronae that span Miranda's surface. These are large oval or trapezoid ranges of troughs and ridges that are each at least 124 miles wide. The three coronae on Miranda are called Arden, Elsinore and Inverness, which are all names of locations in some of Shakespeare's plays.**

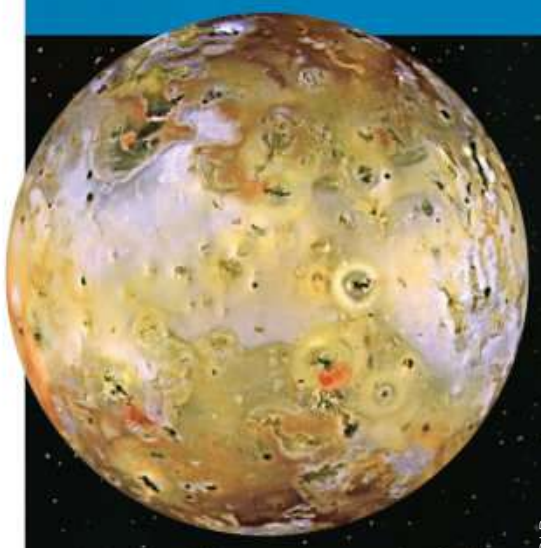
**There isn't a consensus among scientists as to what processes might be responsible for Miranda's coronae, but some believe that its surface is the result of many collisions with space debris. Others have suggested that the coronae originally formed as domes of ice on the surface, causing the rock beneath to collapse and form coronae. Scientists still don't know what the whole moon looks like. So far only the southern hemisphere has been captured by NASA's Voyager 2 spacecraft.**



An image of Miranda captured by NASA's Voyager 2 probe, 24 January 1986

© NASA/JPL-Caltech

**AR ZONE! SCAN HERE**



There are over 400 volcanoes on Io's surface, with as many as 150 erupting at once

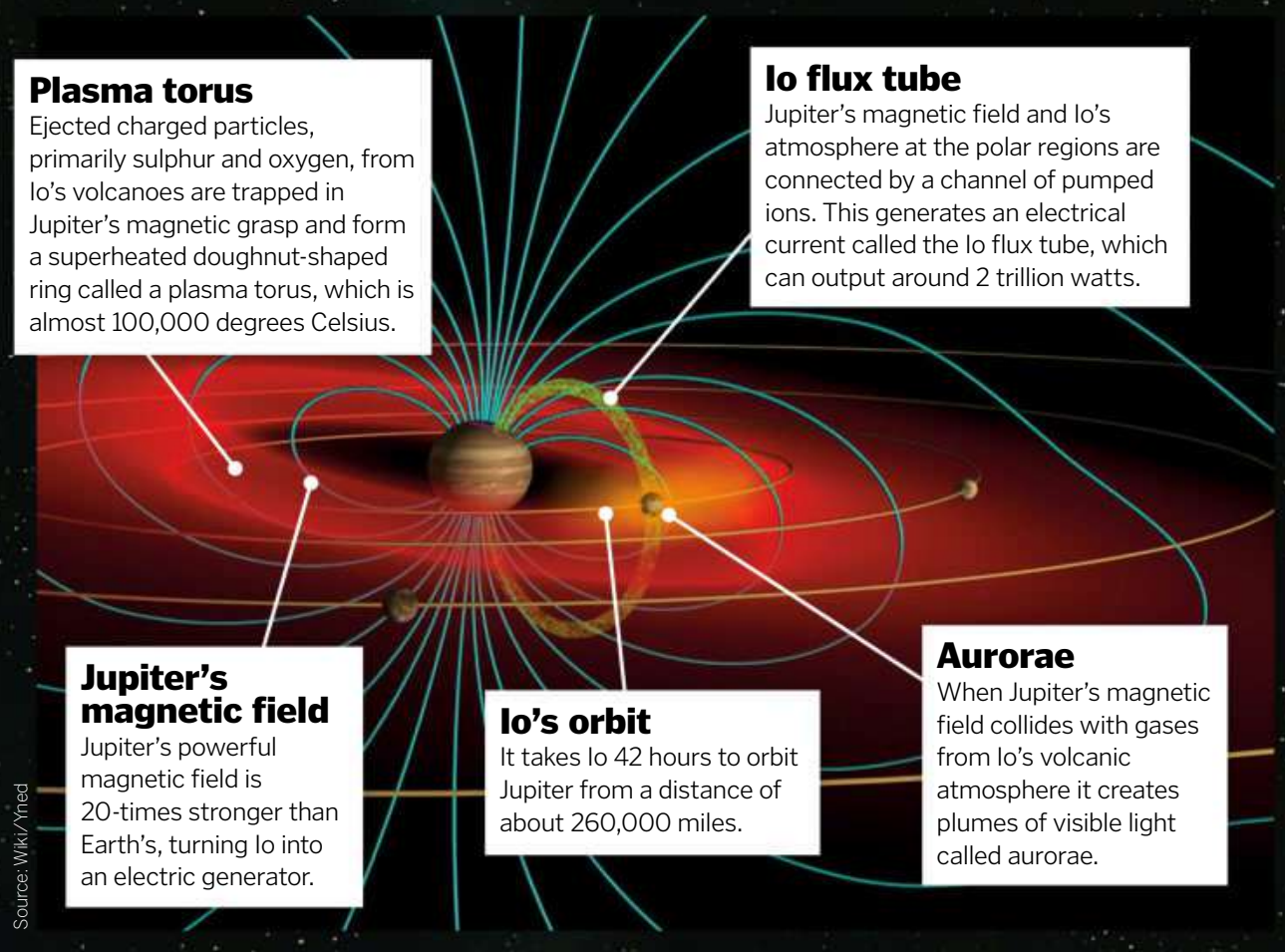
© NASA/JPL/University of Arizona

A volcanic plume erupting on the surface of Io

© NASA/JPL/DLR

# Io's volcanic umbilical cord

Discover how Io's violent nature has created strange tunnels to Jupiter


Plasma torus
Ejected charged particles, primarily sulphur and oxygen, from Io's volcanoes are trapped in Jupiter's magnetic grasp and form a superheated doughnut-shaped ring called a plasma torus, which is almost 100,000 degrees Celsius.
Io flux tube
Jupiter's magnetic field and Io's atmosphere at the polar regions are connected by a channel of pumped ions. This generates an electrical current called the Io flux tube, which can output around 2 trillion watts.
Jupiter's magnetic field
Jupiter's powerful magnetic field is 20-times stronger than Earth's, turning Io into an electric generator.
Io's orbit
It takes Io 42 hours to orbit Jupiter from a distance of about 260,000 miles.
Aurorae
When Jupiter's magnetic field collides with gases from Io's volcanic atmosphere it creates plumes of visible light called aurorae.

Source: Wiki/Yned

# Explosive surface

Name Io
Planet Jupiter
Size 3.5x smaller than Earth
Discovered 1610

**Io is just one of the many moons of Jupiter, but what makes it stand out from the rest is its violent volcanic activity. Hundreds of active volcanoes cover Io's surface, ejecting molten lava as high as 300 miles into the air. Unlike volcanoes on Earth, Io's violent eruptions are the result of gravitational interactions with Jupiter and some of the other moons in orbit. Jupiter's gravitational pull is 2.4-times greater than Earth's and can cause the surface of Io to be stretched and compressed, bulging up to as much as 100 metres wider. This gravitational to and fro causes friction and cooks the moon's interior in a process called tidal heating. Some researchers believe that tidal heating has formed a river of molten rock deep in Io's interior, and that's the source of its volcanicity.**

**Earth and Io both host active volcanoes. However, Io's volcanism has created a very different atmosphere to our planet, containing mostly sulphur dioxide. Jupiter and its moons are located in a cooler region of the Solar System, therefore Io experiences a range of temperatures. Its surface can drop to -130 degrees Celsius, and around its volcanoes spikes to 1,649 degrees Celsius, which has led to many referring to the active moon as a celestial body of fire and ice.**

**Dark side**
Dust particles ejected from the surface of one of Saturn's smaller moons, Phoebe, may have collected on Iapetus' surface. The dark material is believed to be composed of cyanides – nitrogen-bearing organic compounds – hydrated minerals and other carbonaceous minerals.

©NASA/JPL/Space Science Institute

# Misshapen moons

Name Pan and Atlas
Planet Saturn
Size 451.8x and 421.9x smaller than Earth
Discovered 1990 and 1980

**Not all moons are mostly smooth spheres of outer space rock, and definitely not Saturn's flying saucer satellites, Pan and Atlas. This lunar pair both have a central rocky bulge surrounded by a protruding ridge – Atlas is only 11 miles from pole to pole, but is 25 miles across its body.**

**Pan and Atlas are two of the closest inner moons to the planet, meaning Saturn's gravitational grip on them is strong. So strong, in fact, that tidal forces can rip them apart or force them to collide with other space rocks. Rather than the gradual collection of rock and dust a typical moon will undergo during formation, these ravioli moons are believed to be the creation of direct collisions between two previously orbiting 'moonlets'. This would account for the flattened surface and equatorial ridges on Pan and Atlas. Although these moons are well known for their shape, they are not alone. A 2018 study from the University of Bern, Switzerland, found that 20 to 50 per cent of Saturn's inner moons share the equatorial ridge and have an elongated shape.**

© NASA/JPL-Caltech/Space Science Institute

These images of Atlas (above) and Pan (right) were taken by NASA's Cassini spacecraft

**Light side**
The lighter side of the moon faces the Sun, whereas the dark side looks upon Saturn. Light reflects brightly from the moon's frozen surface, which is mainly composed of ice, carbon dioxide, mineral iron and iron oxide.

# Two-faced

Name Iapetus
Planet Saturn
Size 8.7x smaller than Earth
Discovered 1671

**Orbiting around 2.2 million miles from Saturn, Iapetus is an icy moon that bears two faces. Iapetus is almost entirely frozen, with a mean global density only slightly above that of ice. Just two per cent of its total mass is rock, and its surface temperature can plummet as low as -183 degrees Celsius.**

**What makes Iapetus special is its different hemispheres, which are noticeably split into sides where one is darker than the other. There have been many explanations as to why Iapetus has a permanent dark side, but the prevailing theory is that another of Saturn's moons, Phoebe, is to blame. Phoebe kicks up cosmic dust into space by being bombarded with micrometeorites, forming a ring around Saturn. Half of Iapetus passes through the ring while it orbits in the opposite direction. As if moving through a cloud of soot, Iapetus collects dust on its surface as it goes.**

**Another unusual feature of Iapetus is its perfect seam: a 12-mile-high, 124-mile-wide mountain range forms a ridge around 75 per cent of the planet. It's a ridge like no other in our Solar System – one that still has astronomers scratching their heads. Some planetary scientists are of the opinion that the ridge formed as a result of Saturn's gravitational pull causing the moon's interior to heat up and bubble out at the equator. Others think that a long-lost moon or asteroid barrage may have collided with an ancient Iapetus to create the ridge.**

**AR ZONE! SCAN HERE**

© NASA/JPL-Caltech/Space Science Institute

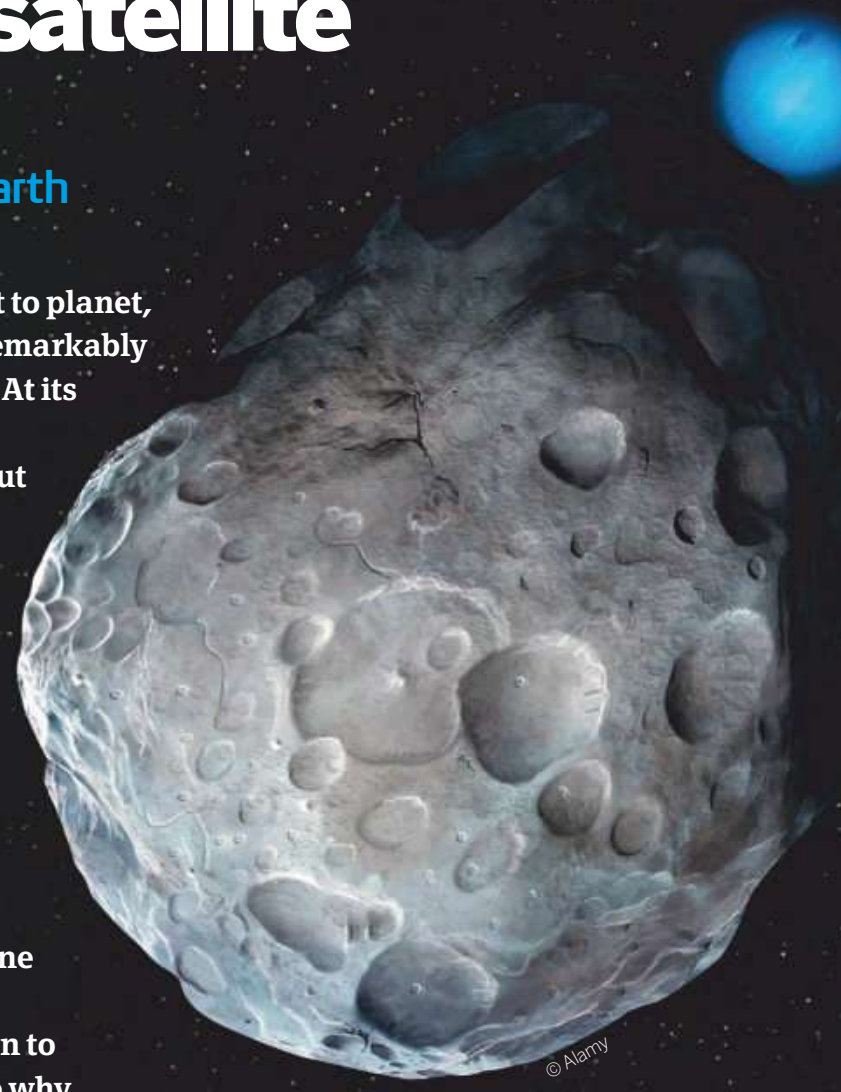
Iapetus is Saturn-facing, so the Cassini spacecraft was only able to image its southern hemisphere

# Slingshot satellite

Name **Nereid**
Planet **Neptune**
Size **37.5x smaller than Earth**
Discovered **1949**

**A moon's orbit differs from planet to planet, but Neptune has a moon with a remarkably elongated orbit unlike any other. At its closest approach, Nereid passes Neptune at 851,280 miles away, but the furthest point in its orbit can extend 6 million miles from its host. It's been suggested that Nereid was once a captured asteroid or object from the Kuiper Belt that was drawn in by Neptune's gravitational pull.**

**Nereid has a prograde orbit, which means it follows the same direction of orbit as Neptune, as opposed to other moons of Neptune such as Triton, which moves in retrograde – the opposite direction to Neptune. It remains unclear as to why Nereid's path around its planet is so eccentric, but some hypotheses point to Triton being the cause. During Triton's capture into Neptune's orbit, it may have acted as a bulldozer, sending existing moons to the planet's surface or causing collisions which evicted them from orbit. Nereid and Triton may have previously come to blows, sending Nereid on its unusual orbit.**



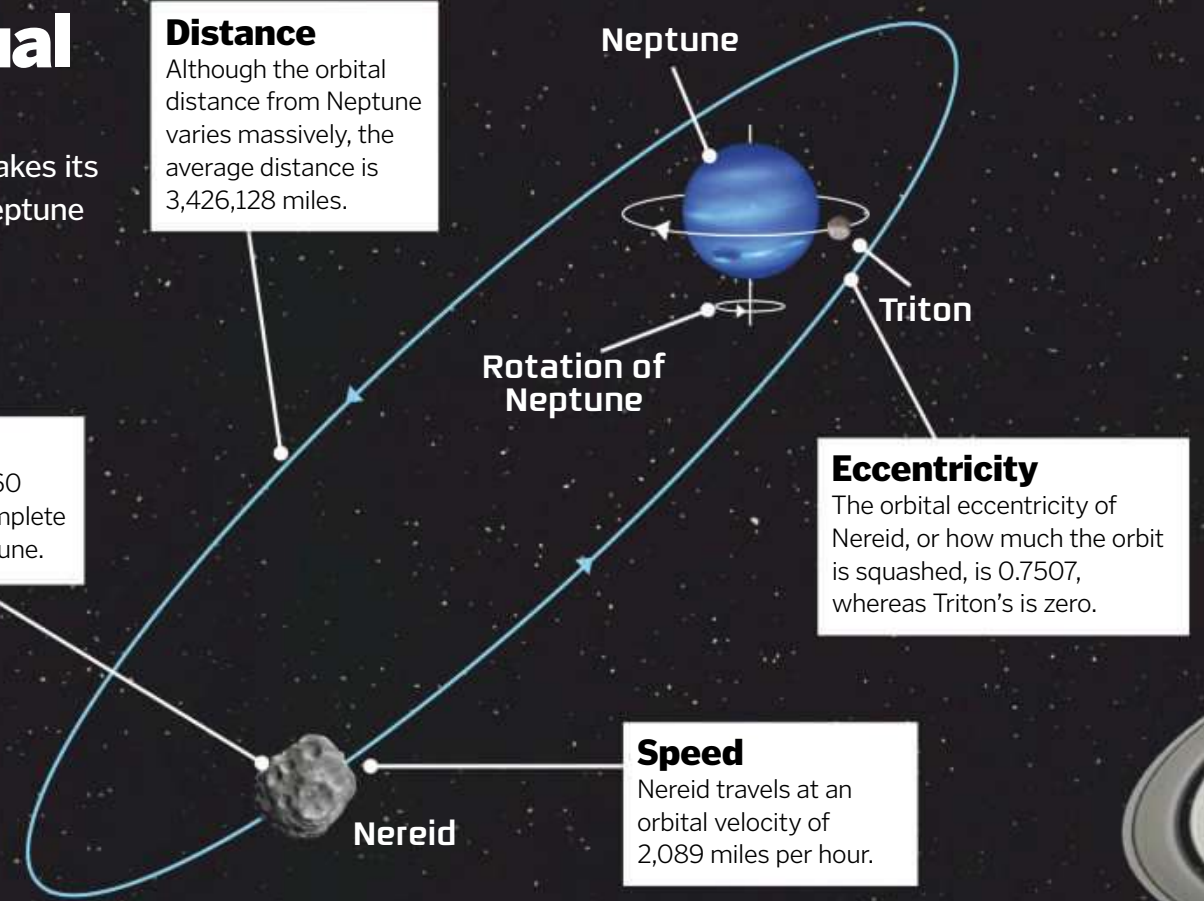
© Alamy

© NASA/JPL

Nereid was first seen by astronomer Gerard Kuiper in 1949. It was the last satellite of Neptune to be discovered before Voyager 2's discoveries in 1989

## Unusual orbit

How Nereid makes its way around Neptune




**Distance**
Although the orbital distance from Neptune varies massively, the average distance is 3,426,128 miles.

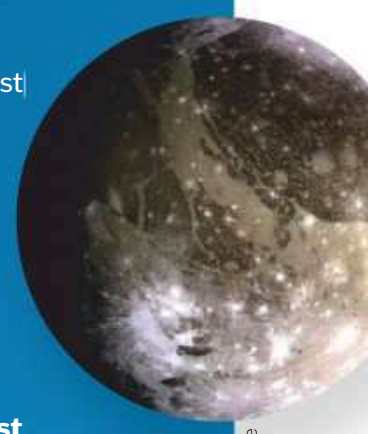
**Duration**
It takes Nereid 360 Earth days to complete one orbit of Neptune.

**Eccentricity**
The orbital eccentricity of Nereid, or how much the orbit is squashed, is 0.7507, whereas Triton's is zero.

**Speed**
Nereid travels at an orbital velocity of 2,089 miles per hour.

Images in diagram © Getty

## 5 FACTS ABOUT RECORD-BREAKING ROCKS



© NASA/JPL/Galileo Probe

**1 Biggest**
The title of largest moon goes to Ganymede, a 3,270-mile-wide natural satellite that orbits Jupiter. Ganymede is also bigger than the planet Mercury.

© NASA/JPL-Caltech/University of Arizona

**2 Most cratered**
The surface of Callisto, Jupiter's second-largest moon, is 100 per cent covered in impact craters.

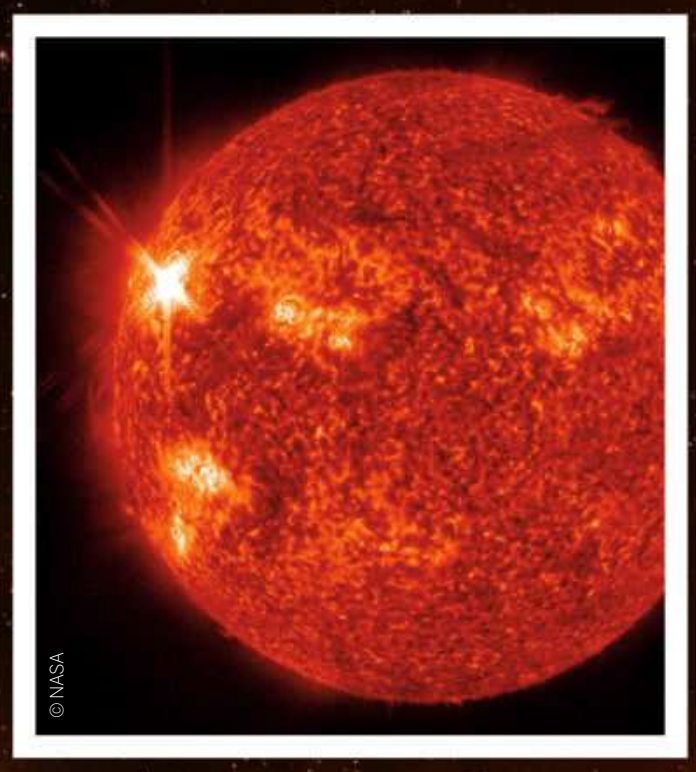
**3 Coldest**
Our Moon has the coldest spot in the entire Solar System. A dark crater at the Moon's south pole stays at a constant -240 degrees Celsius, which is colder than Pluto by ten degrees Celsius.

**4 Smallest**
The award for smallest known moon in the Solar System goes to Deimos. This tiny moon orbits Mars and is only around 6.8 miles wide. However, there are potentially many smaller 'shepherd moons' that orbit Saturn which might take the record.

**5 Most moons**
Saturn has the most moons in our Solar System, with an impressive haul of 82. The previous record holder was Jupiter with 79, but 20 new moons around Saturn were discovered in 2019.

# Life cycle of the Sun

From birth to its death in the far future, our Sun's evolution is driven by fundamental forces




The Sun in the prime of life, as seen by NASA's Solar Dynamics Observatory

**The Sun is just one of billions of stars in the galaxy, and we see others in all stages of their evolution – some much older than the Sun, others younger. By combining these observations with our understanding of nuclear physics, we can reconstruct a complete life cycle for the Sun.**

**The space between stars is filled with tenuous gas, mainly hydrogen, with smaller amounts of heavier elements. Given enough time, this gas is all that's needed to make new stars. A region that happens to be slightly denser than its surroundings will contract, pulling in more gas due to its higher gravity. This increases the density further, and in turn temperature and pressure also rise. Eventually the contracting ball of gas becomes a protostar, glowing dimly in the infrared from its internal heat.**

**The protostar continues to accrete the surrounding matter, increasing its own mass and – in the case of stars like our own Sun – forming a nascent planetary system around it. Inside the star, gas pressure eventually counterbalances the force of gravity and prevents further collapse. At this point the core temperature is high enough to trigger nuclear reactions, fusing hydrogen into the next lightest element, helium, and producing vast amounts of heat and light in the process. This phase of the star's life is called the 'main sequence', and it's where the Sun is now.**

**The more massive a star is, the more efficient it is at fusion, and the less time it spends on the main sequence before moving onto the next stage, becoming a vast, bloated red giant. Fortunately for us, as far as the Sun is concerned this phase still lies billions of years in the future. But even that's not the end, as the timeline below shows.**

## Stellar timeline

How our star has evolved since it came to be

### Sun's temperature
**<2,000 degrees Celsius**

Under the action of gravity, the newborn Sun begins to condense out of a cloud of interstellar gas – this is mainly hydrogen, but with a scattering of other elements.

### 3,000 degrees Celsius

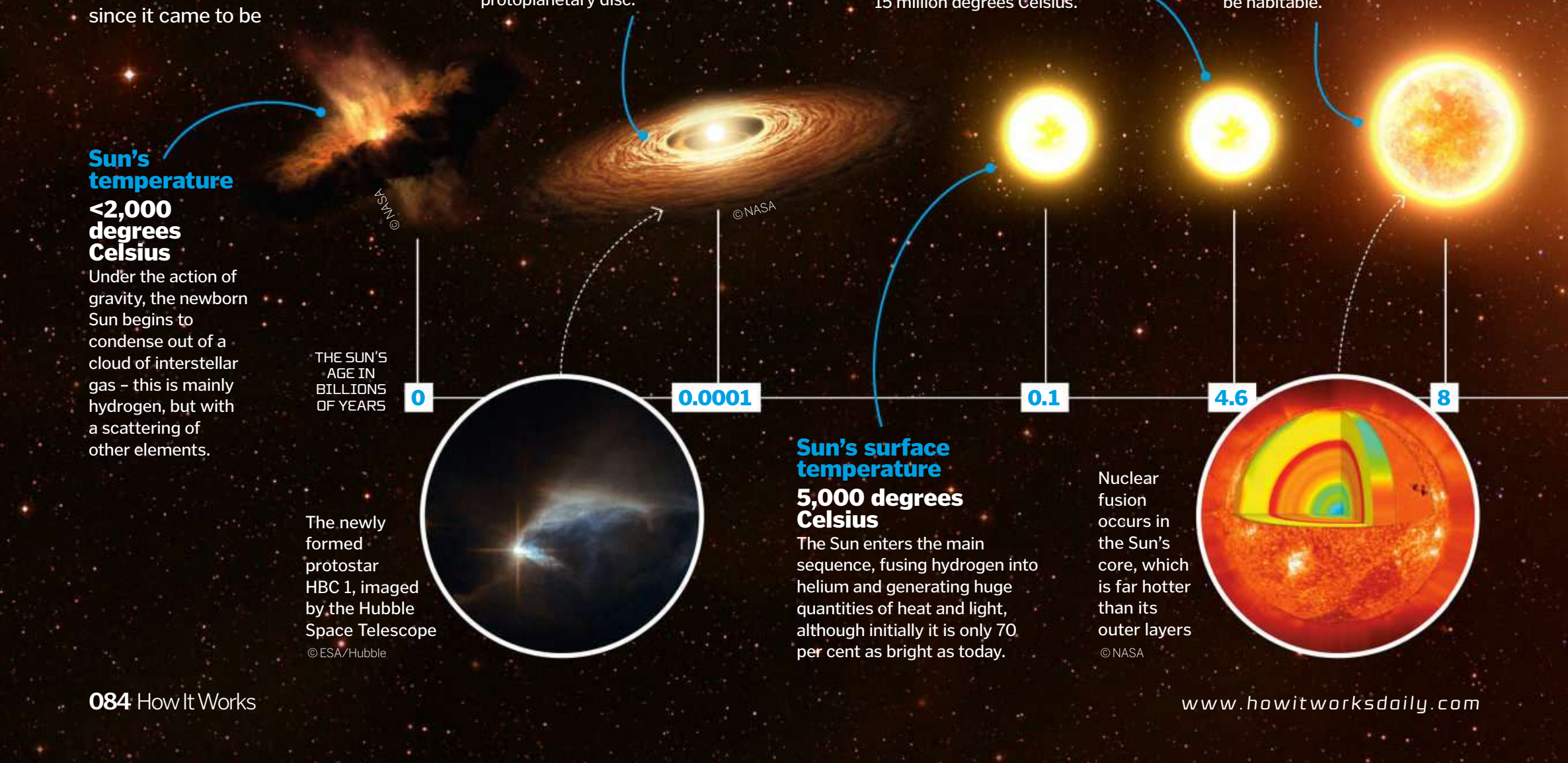
The Sun becomes a protostar, shining dimly thanks to the heat gained by the gas during its collapse. The more rapidly rotating material forms a protoplanetary disc.

### 5,500 degrees Celsius

This is where the Sun is now, around halfway through the main sequence. Nuclear fusion continues deep inside the central core, where the temperature can reach 15 million degrees Celsius.

### 6,000 degrees Celsius

As the Sun proceeds through the main sequence, its luminosity increases. By this point it is 40 per cent brighter than today, and the Earth has become too hot to be habitable.




The newly formed protostar HBC 1, imaged by the Hubble Space Telescope
© ESA/Hubble

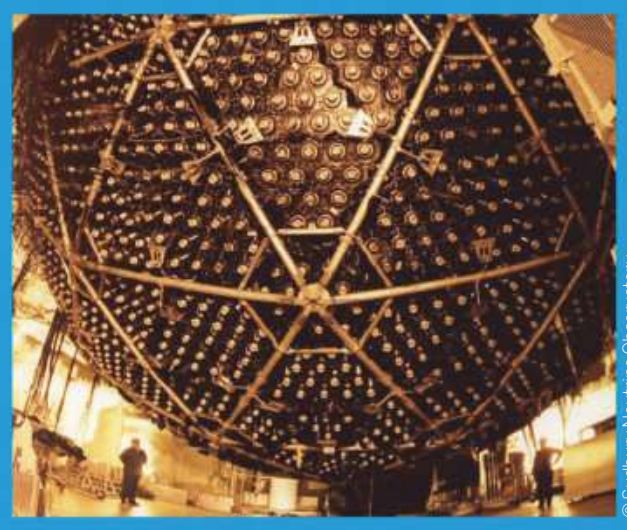
### Sun's surface temperature
**5,000 degrees Celsius**

The Sun enters the main sequence, fusing hydrogen into helium and generating huge quantities of heat and light, although initially it is only 70 per cent as bright as today.

Nuclear fusion occurs in the Sun's core, which is far hotter than its outer layers
© NASA

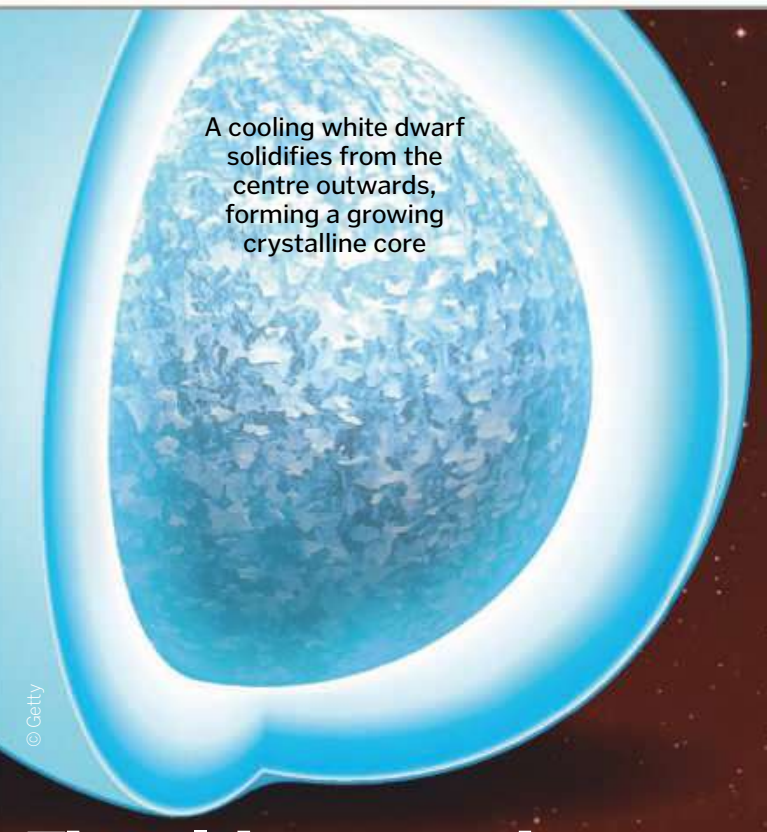
# Looking deep inside the Sun

**For many years our understanding of the internal workings of the Sun – and the implications for stellar evolution – were clever guesswork. Telescopes only tell us about its surface, so scientists had to rely on nuclear theory and computer models. The only way to see what's happening deep inside the Sun involves tiny subatomic particles called neutrinos, but these are extremely difficult to detect. It was only in 2002 that researchers at the Sudbury Neutrino Observatory in Canada finally established that the number of solar neutrinos reaching Earth is exactly what theory predicts should be produced.**



© Sudbury Neutrino Observatory

The Sudbury Neutrino Observatory confirmed our understanding of nuclear processes inside the Sun

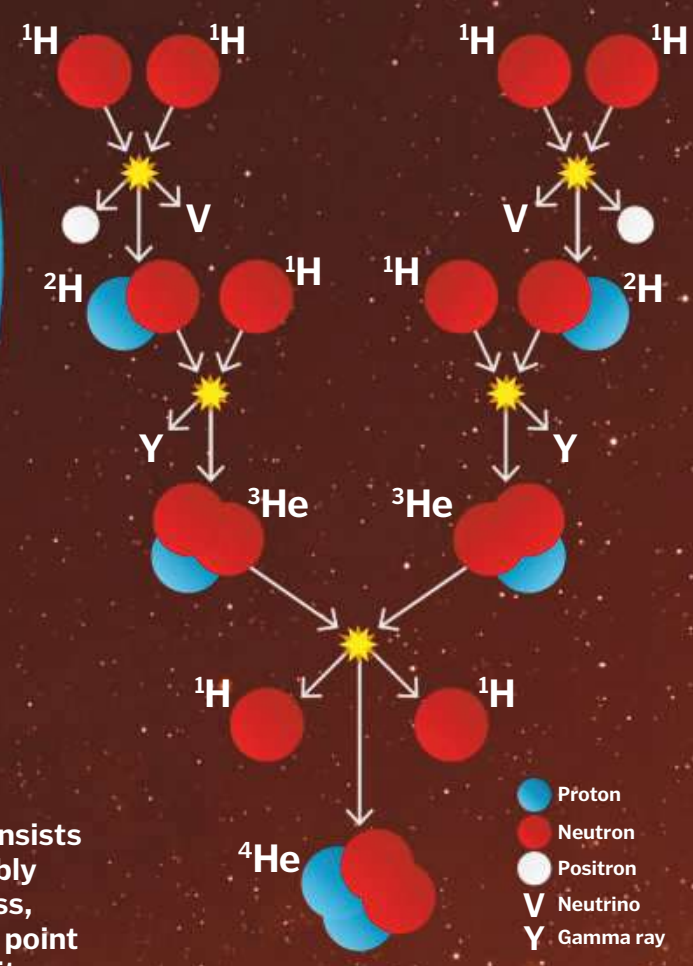


A cooling white dwarf solidifies from the centre outwards, forming a growing crystalline core

© Getty

# The ultimate end

**After collapsing down to a white dwarf, the Sun consists entirely of carbon nuclei compressed to an incredibly high density. It still has around half its present mass, squashed into roughly the volume of Earth. By this point the Sun has stopped producing fusion energy, but it retains the tremendous heat of the stellar core. Initially the surface temperature is higher than at any previous stage of its life cycle – 10,000 degrees Celsius or more – but over time it cools. Eventually it will reach the ambient temperature of surrounding space, just a few degrees above absolute zero. This final state is referred to as a 'black dwarf', but it's purely hypothetical, as the universe isn't old enough for any stars to have reached it yet. In the case of the Sun, it may take a quadrillion years – a hundred thousand times the present age of the universe – before it becomes a black dwarf.**




The Sun's energy comes from the fusion of hydrogen nuclei into helium

The bright star Sirius has a tiny white dwarf companion, shown by the arrow

© NASA

## 4,000 degrees Celsius

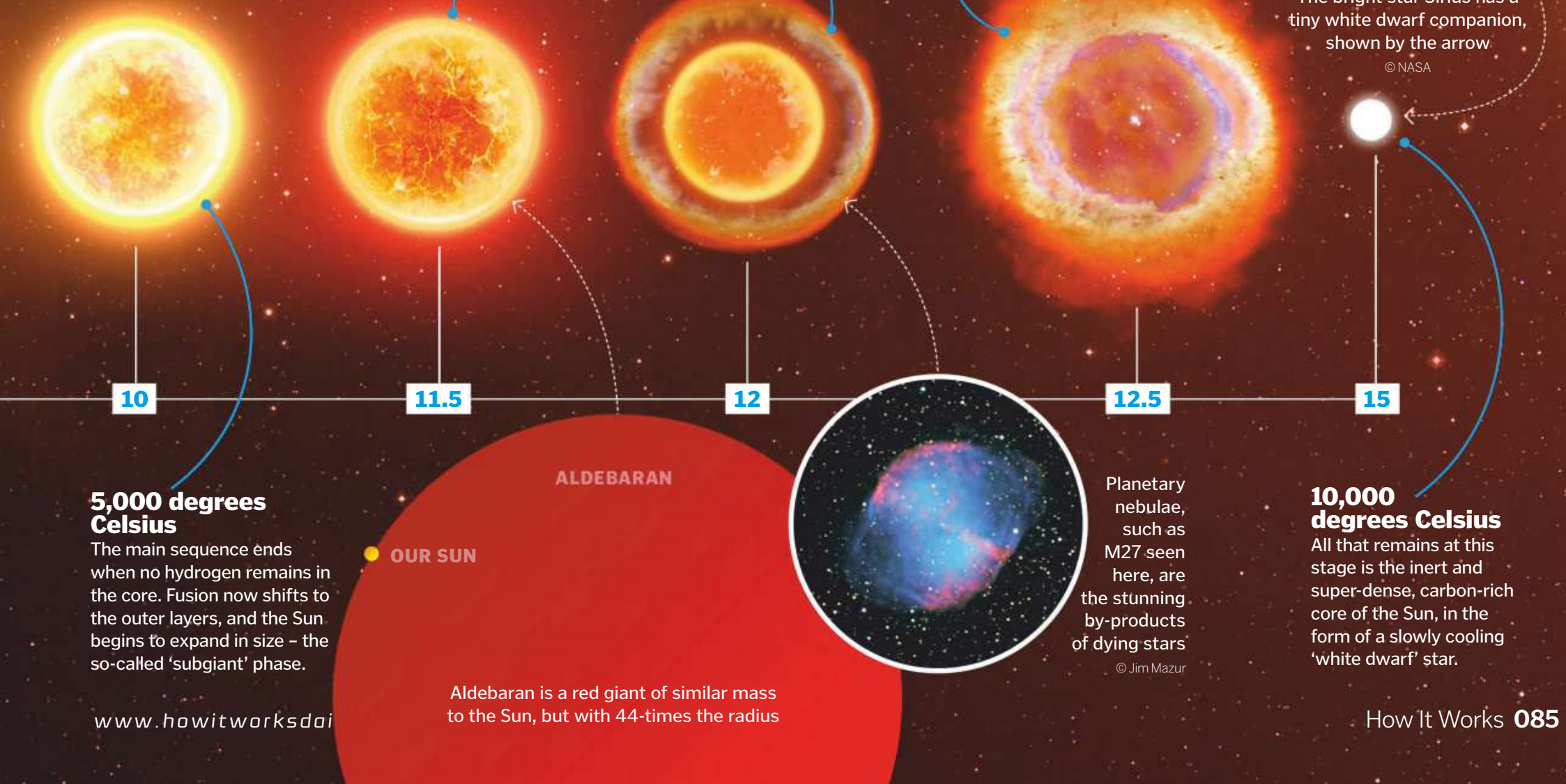
In the brief but dramatic 'red giant' phase, the Sun expands up to a hundredfold in size, becoming enormously brighter, but also cooler and redder – hence the name.

## 30,000+ degrees Celsius

The red giant phase ends when helium in the core abruptly transforms into carbon, releasing a burst of energy which blasts off the outer layers to create a planetary nebula.

## 20,000 degrees Celsius

The planetary nebula, which may have contained 50 per cent or more of the Sun's original mass, dissipates back into the interstellar medium in a form of cosmic recycling.




## 5,000 degrees Celsius

The main sequence ends when no hydrogen remains in the core. Fusion now shifts to the outer layers, and the Sun begins to expand in size – the so-called 'subgiant' phase.




Aldebaran is a red giant of similar mass to the Sun, but with 44-times the radius



Planetary nebulae, such as M27 seen here, are the stunning by-products of dying stars

© Jim Mazur

## 10,000 degrees Celsius

All that remains at this stage is the inert and super-dense, carbon-rich core of the Sun, in the form of a slowly cooling 'white dwarf' star.

# BRAIN DUMP

**Because enquiring minds need to know...**

SPACE

## Why are all Moon craters circular?

**Oliver Bentley**

It's not just Moon craters that are round in shape, meteorite impact craters are almost always round on any planet they hit, despite hitting the surface at a variety of angles. This is because the physical shape of the impactor and the angle of its approach have a fraction of the influence on the crater's shape compared to the enormous kinetic energy released by the impact. You might get an elongated crater if the impactor came in at an extremely shallow angle, grazing the surface and releasing its impact energy in a long shape instead of at a single point. But these are very rare. **BB**

Mars is home to an elongated crater 236 miles long, called Orcus Patera. Its origin is unknown, though it could have been created by an ancient meteorite

© ESA

**WANT ANSWERS?**
Send your questions to...

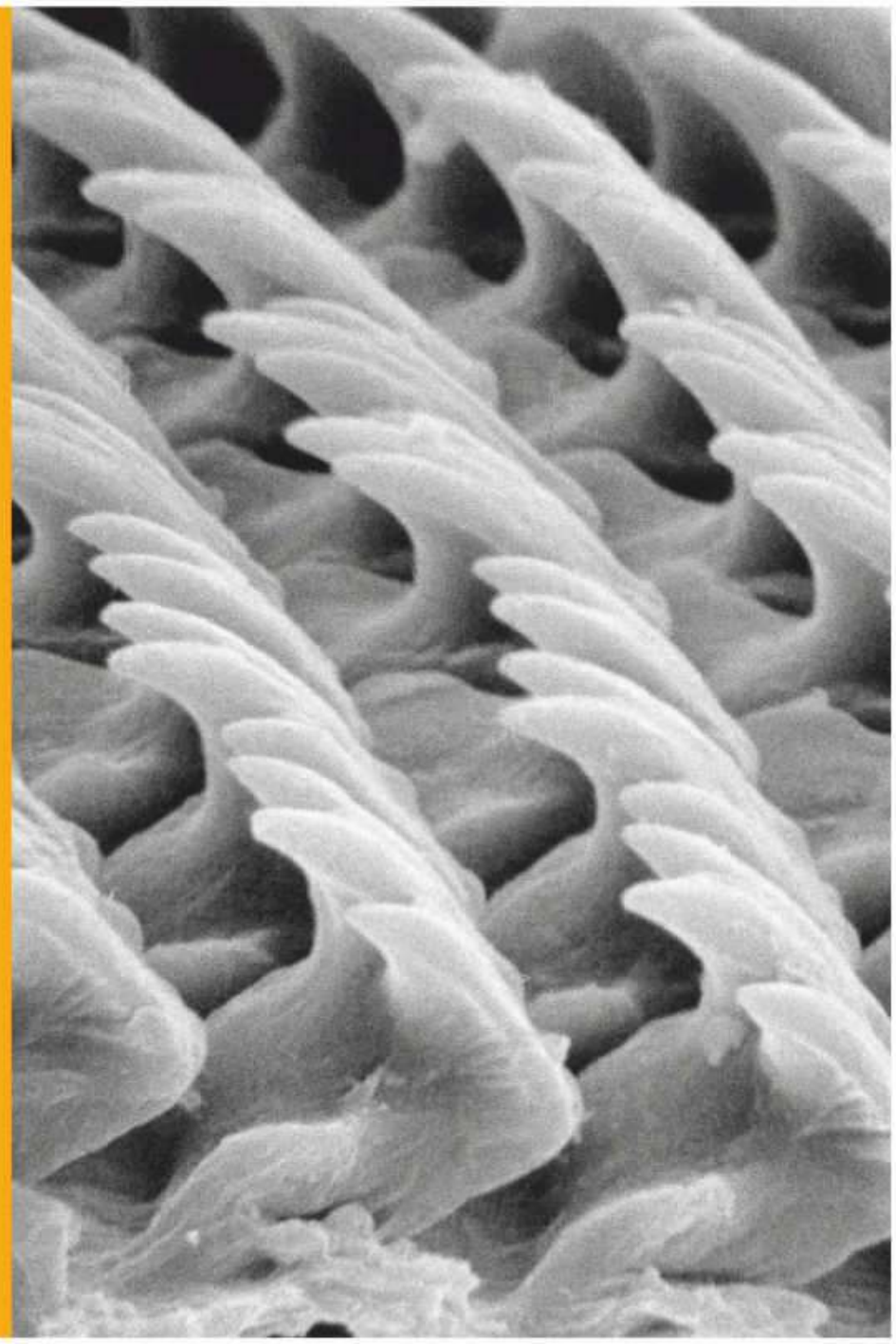
How It Works magazine @HowItWorksmag @howitworks@futurenet.com

ENVIRONMENT

## How many teeth does a snail have?

**Max Hall**

The average garden snail has around 14,000 microscopic 'teeth' that run along a flexible structure called a radula. They use these teeth to grind and break down the leafy greens they eat. The rows of teeth appear like Velcro, with each tooth hooked inwards, making it easy for the snail to latch onto their food and transport it into their bodies. These teeth undergo a continual cycle of regrowth. New rows will grow at the back of the mouth and slowly move to the front as the front rows wear and fall away. **SD**



Some species of snail have been found to have as many as 20,000 teeth in their mouths

© A amy

© A amy

SCIENCE

## How can Pyrex be put in the oven and the freezer?

**Jeff Jacobs**

Pyrex glassware is made from heat-resistant borosilicate glass and can withstand temperatures between -40 and 300 degrees Celsius. They have high thermal shock resistance so can be used safely in the freezer and oven and the other way around. **SD**

© Roberto Westbrook/ Getty Images

Noise-cancelling headphones help to block out surrounding distractions

TECHNOLOGY

## How do noise-cancelling headphones work?

**Louis Tyndall**

To reduce any external sound that might be disruptive or interrupt your listening, these headphones can work actively or passively. Passive methods of noise reduction are achieved through materials used to block and absorb sound waves. This is usually done using layers of high-density foam and can make the headphones feel heavier.

These devices can also create their own sound waves to mimic incoming noise. This is the active method. By timing the peaks of the new waves to align with the troughs of the background noise, the external sound is cancelled out. For this to be achieved, extra components are needed, such as a microphone to listen to external noise and electronics in the ear piece that can create a copy of the waves detected. **AH**

### DID YOU KNOW?

**The world's biggest gearbox weighs 86 tonnes – it's for an offshore wind turbine**

WiFi routers are continuously converting binary code into radio frequencies, and vice versa, to deliver you internet access

© Getty

TECHNOLOGY

# How does WiFi work?

**Clair Grant**

When you access the internet on your smart device via WiFi, the request is turned into binary code – ones and zeroes – then translated into specific radio frequencies, typically 2.4 GHz and 5 GHz, and sent to your WiFi router. The router then translates the frequency back into binary and gathers the requested information via the internet cable. The obtained information is then converted from binary into radio frequency and sent back to your smart device. **SD**

# BRAIN DUMP

SCIENCE

## When were magnets first discovered and used?

**Archie Swain**

English physicist William Gilbert was the first person to study magnetism in depth, publishing his results in 1600. He outlined the difference between static and magnetic attraction, as well as discovering that Earth has two magnetic poles. One of the first practical uses of magnets was developed by the Vikings – they used a compass-like tool made from lodestone and iron to navigate. **AH**

© Getty Images/ Andrzej Wojcik

### DID YOU KNOW?

**The average person will yawn 20 times a day**

SCIENCE

## Why do we yawn?

**Sunnah Safdar**

Scientists are not entirely certain about the purpose of yawning, although some speculate it's a thermoregulatory system to control brain temperature. When our body's temperature is warmer we feel tired, so yawning may occur to help prompt the onset of sleep by lowering our temperature, which typically happens when we sleep. Studies of mice have found that after yawning, the temperature of their brains decreased before sleeping. **SD**

Studies have found that the bigger your brain, the longer you yawn for

© Getty

© Getty

TRANSPORT

## How does a car gearbox work?

**Keri Ball**

The pistons in a car's engine have to pump constantly to stop the engine cutting out. So to stop the car flying off at top speeds, the gearbox controls how much of this power gets to the wheels. Cogs and shafts inside the gearbox create different ratios of speed and torque – these are the gears. **BB**

© Getty

NASA's MOXIE is capable of generating small amounts of oxygen from Mars' atmosphere

SPACE

## Do you think it might be possible to change the environment of Venus or Mars to make it habitable?

**Chris Lucas**

The environments of Mars and Venus are relatively similar to that of Earth's, even though they are hostile to human life. We might be able to change them one day by terraforming: adapting the atmosphere of terrestrial planets to make them breathable, with a habitable humidity and temperature. NASA is currently testing equipment designed to produce oxygen from Mars' atmosphere. It works by taking in carbon dioxide, which makes up 96 per cent of the planet's gas, and splitting it electrochemically to release oxygen. It's a tentative step towards a colony on Mars. **BB**

© NASA

SPACE

## How far into space have humans travelled?

**scimaxfacts on Instagram**

The record for the greatest distance from Earth stands at 248,655 miles. It was set in April 1970, when the crew of NASA's Apollo 13 mission – Jim Lovell, Jack Swigert and Fred Haise – swung around the far side of the Moon. **BB**

© Catherine McQueen/ Getty Images

SCIENCE

## What causes anxiety?

**Ellie Meredith**

Anxiety is a feeling of unease or worry that can be experienced by anyone, ranging in severity, but can also be a result of a specific condition called generalised anxiety disorder. This condition creates long-term anxious feelings over a larger range of situations, as opposed to a single fearful event. The exact cause of this condition is unknown, and can differ for each person. Scientists believe anxiety is a combination of genetic and environmental causes. Areas of your brain controlling the fight-or-flight response react similarly to when perceiving physical or mental threats. These areas may be more active in those who suffer from anxiety. **AH**

Shortness of breath is one common symptom of anxiety

### DID YOU KNOW?

**Noise-cancelling headphones were first invented for aeroplane pilots**

SCIENCE

## Why do objects have different terminal velocities?

**Leonard Cooper**

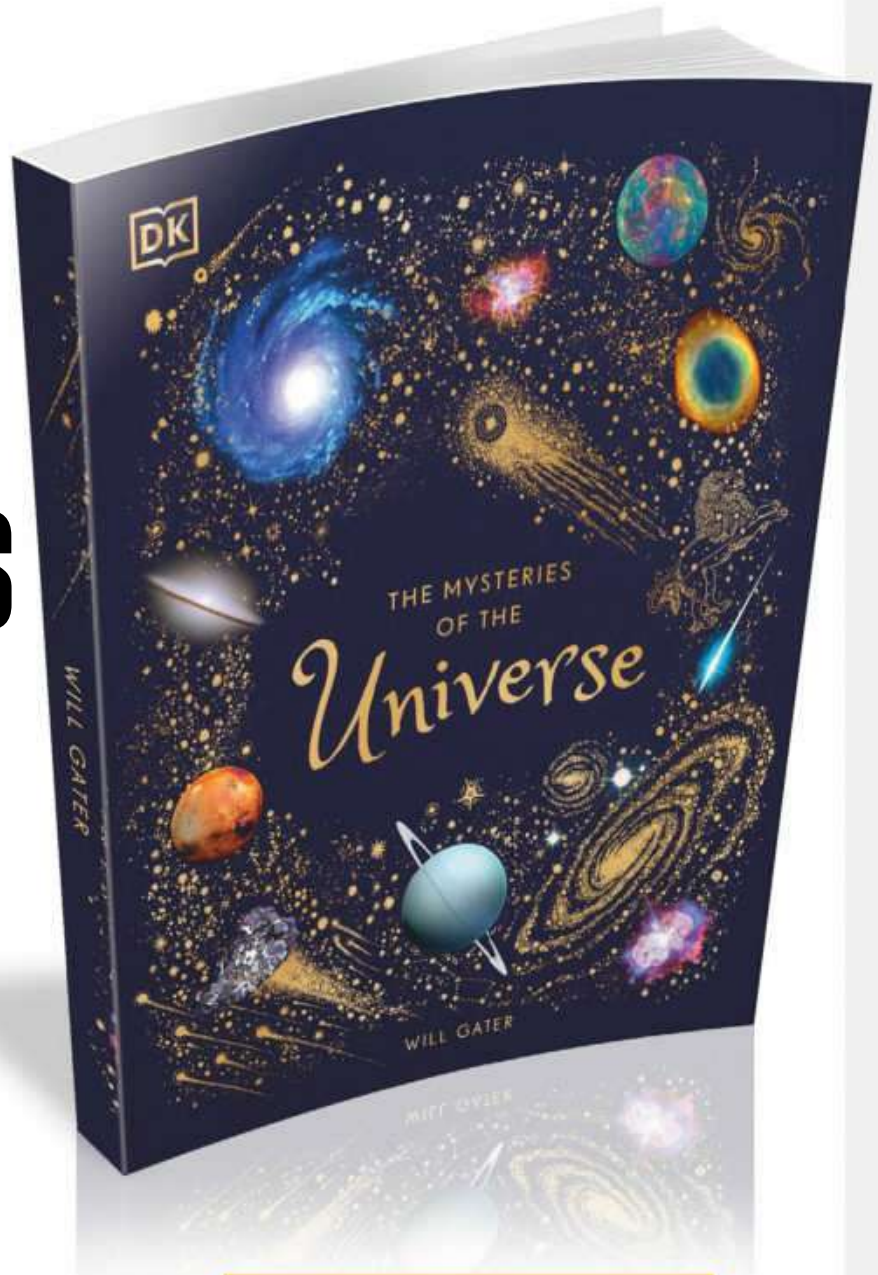
Terminal velocity refers to the maximum velocity an object can reach while falling. At terminal velocity the forces moving the object – the weight of the object – are balanced by frictional forces – air resistance. Factors affecting an object's terminal velocity include its mass, surface area and acceleration due to gravity. More massive objects will accelerate to a higher velocity before the upward force of air resistance balances the downward force of gravity. Objects that have a larger surface area will have more space for air resistance to work on and a smaller terminal velocity. However, in a vacuum every object would fall at the same velocity because there is no air surrounding it, therefore there's no air resistance. The only force present is gravity. **AH**

Skydivers reach terminal velocity at approximately 120 miles per hour

© Getty Images/ Reto Nyffenegger

# BOOK REVIEWS

The latest releases for curious minds




## Mysteries of the Universe

### THE COSMOS IN A NUTSHELL

- Author: **Will Gater**
- Publisher: **DK Children**
- Price: **£20 / $19.99**
- Release: **Out now**

The universe only becomes slightly less mysterious with age, but for children it can be a truly mind-blowing place to exist in. Beyond the Kármán line, which demarcates Earth's border with outer space, are a myriad of beautiful objects and alien worlds. Most of these we don't fully understand and can't describe in proper detail, and they're all the more beguiling for this mystique. This is what author Will Gater has tried to encapsulate in *The Mysteries of the Universe*, a hardback replete with illustrations and eye-catching photos of objects found right across the breadth of the universe.

The book begins right here on planet Earth, exploring our immediate cosmic surroundings and what you can see with the naked eye from the ground. Gater takes us on a journey from the centre of our Solar System, exploring the Moon, the Sun, the planets and other objects, right out to the edge of interstellar space. From there we explore our galactic locale – exoplanets, giant stars, black holes and nebulae – and then we're taken billions of light years away, past other galaxies to the furthest reaches of space that we've ever observed.

*Each object is described in language that anyone can understand*

Each object is described in language that anyone can understand, peppered with facts and stats that give a real sense of the scale and majesty of space. Annotated images help illustrate Gater's points, but often all that is needed is a large photo of the object, usually taken by one of NASA's telescopes or another space agency.

It's an accessible and fun book to read that's especially suitable for younger readers who might be starting an astronomy hobby. But whether they have a special interest in space or not, it's bound to fire their imaginations. We can't imagine anyone who wouldn't want to flick through and bask in the awesome *Mysteries of the Universe*.

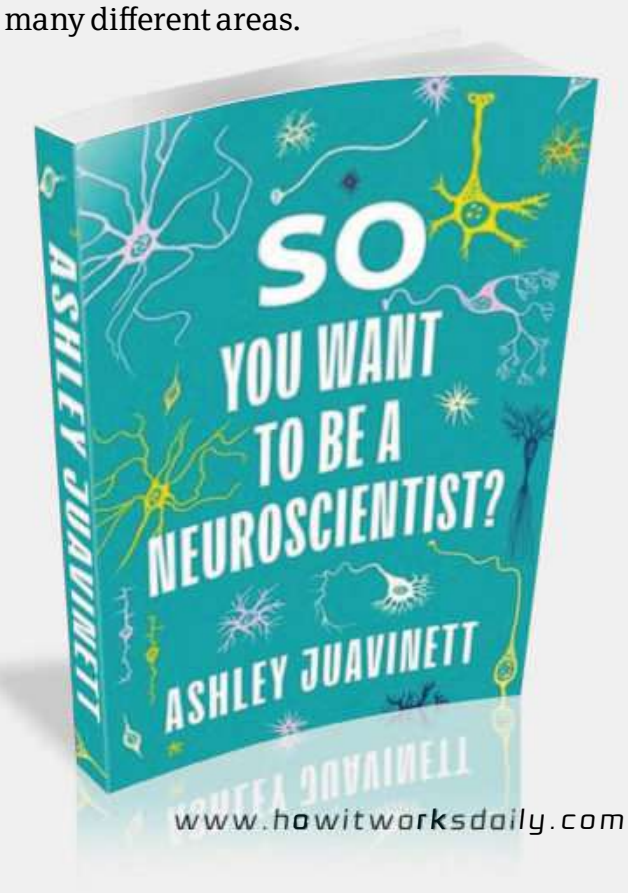
## So You Want to Be a Neuroscientist?

### EVERYTHING YOU NEED TO KNOW ABOUT PURSUING A CAREER IN ONE OF THE TOUGHEST SUBJECTS

- Author: **Ashley Juavinett**
- Publisher: **Columbia University Press**
- Price: **£14.99 / $19.95**
- Release: **Out now**

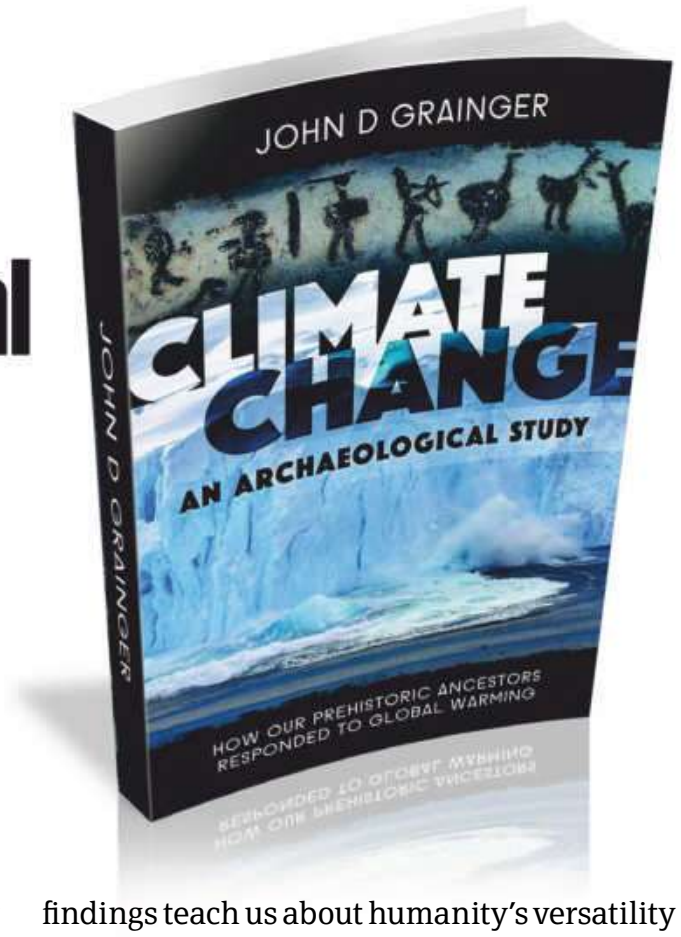
If you've ever dreamed of being a brain surgeon or a neuroscientist, this book is a must-read. Not only does it delve into the history and science behind neuroscience, but challenges the reader on why they want to get into the field. Better yet, it offers sound advice on how best to be successful in it.

This book is perfect for any college student considering their options for university or a graduate looking to further their career. It will help anyone battling with the idea of entering this field and remains frank and honest about their potential career paths. It also speaks about the future of the field, how different areas of science will collaborate in the study of the brain, and how the reader's career could diversify into many different areas.



# Climate Change: An Archaeological Study

## HOW OUR ANCESTORS RESPONDED TO GLOBAL WARMING



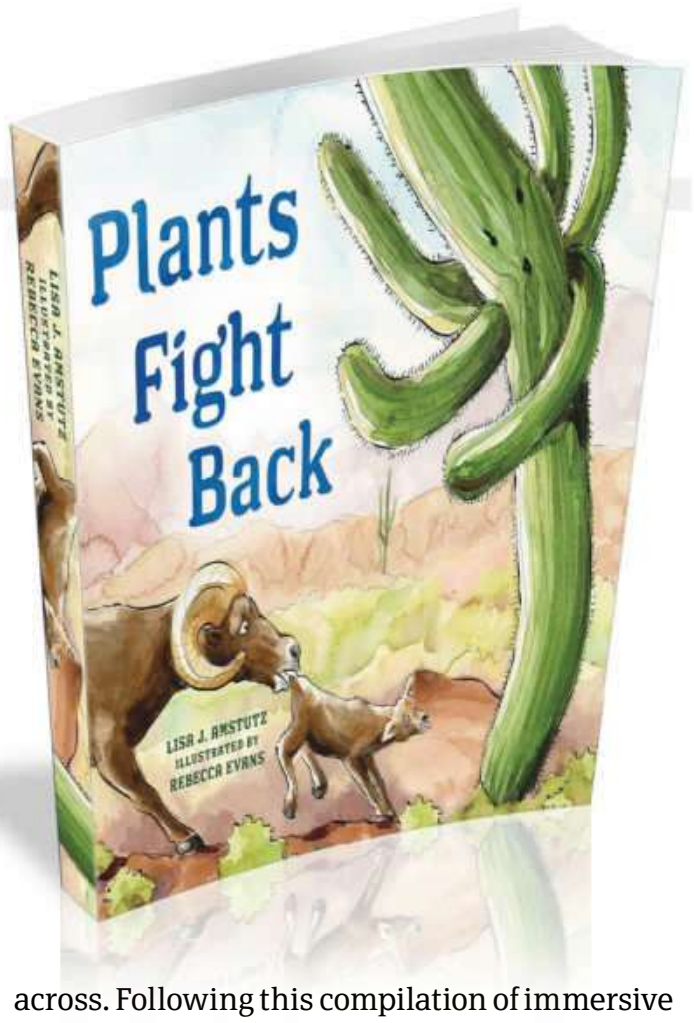

- Author: **John D. Grainger**
- Publisher: **Pen and Sword History**
- Price: **£25.00 (approx. $33.00)**
- Release: **Out now**

Climate change is often talked about – especially now as the world tries to predict what our warming planet will become – but this book offers something different to the ongoing environmental debates. Referring back to times long before climate change studies, it evaluates humans' natural ability to adapt to temperature shifts long before our time. Although their circumstances will have been largely different from the upcoming changes today's civilisations face, between 15,000 and 8,000 years ago our ancestors had to live through the last significant case of global warming.

Grainger expertly dissects relevant archaeological evidence to explain what these findings teach us about humanity's versatility during our occupation of the globe. Filled with surprising information, such as the unlikely patterns seen within separate communities, this book allows you to explore how people adapted their hunting, travelled the globe and ultimately survived as continents rapidly changed around them, with much less foresight than we have. This book will leave you thinking about just how much the world has changed, and how different our approaches are to today's climate crisis.

# Plants Fight Back

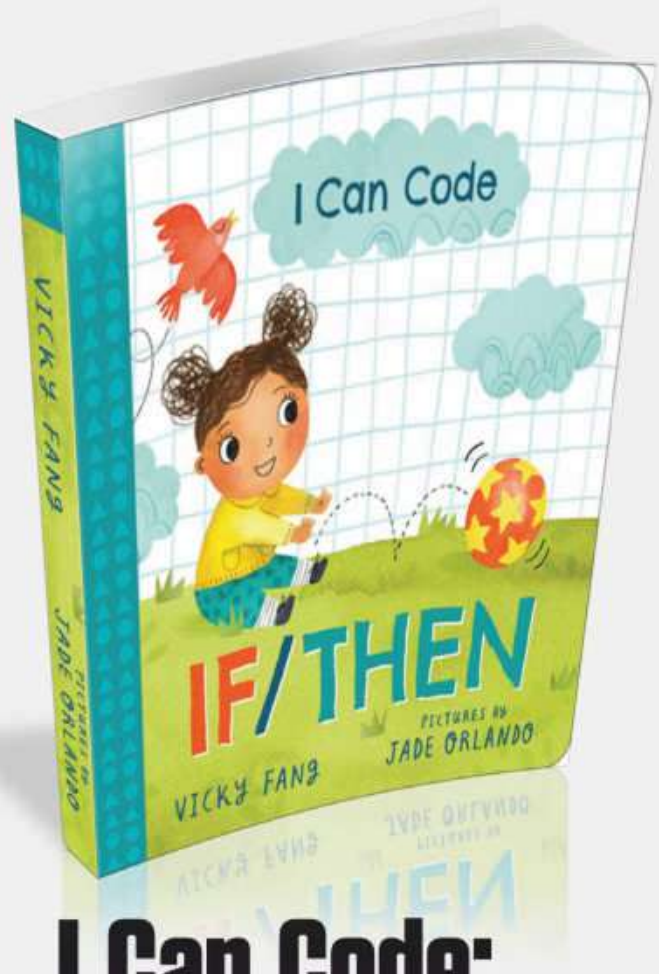
## THE PLANTS THAT STAND THEIR GROUND




- Author: **Lisa J. Amstutz**
- Publisher: **Dawn Publications**
- Price: **£6.73 / $8.99**
- Release: **Out now**

It can be difficult to imagine how a rooted plant can fight off predators. But with this book, a new technique is learned with each rhyme. From camouflage tricks to secret signals, it teaches children the diverse ways in which plants can escape danger. The visual layout of the book captures each species' unique defence with clear and appealing illustrations, assisting children in better understanding what they've read. There is also a separate section on each page to provide further details about these intriguing plants.

*Plants Fight Back* gives young readers an insight into species they may not have come across. Following this compilation of immersive illustrations, there are photographs of each plant at the back to show their appearance and provide more fun facts. This engaging and educational book is a suitable read for five to nine year olds, with the capability to expand the knowledge of young minds and connect them with the wonders of the natural world.




# I Can Code: If/Then

## BRINGING KIDS UP TO SPEED WITH CODING

- Author: **Vicky Fang**
- Publisher: **Sourcebooks Explore**
- Price: **£6.84 / $8.99**
- Release: **Out now**

Coding seems to be a technological language that the youth of today are quickly learning, and at an increasingly younger age. This is a fact that has prompted author Vicky Fang to write this children's guide to coding. Fang takes simple examples to explain cause and effect in coding, such as 'if I push this ball, then it rolls away', and translates that into what you'd see in a line of code. The book is extremely easy to follow, even for a younger child, and is a great way to introduce them to the topic of coding. The book does solely focus on one aspect of coding, but Fang's other book on the subject, *I Can Code: And/Or*, will offer more information.

*The book is extremely easy to follow*

# BRAIN GYM

## GIVE YOUR BRAIN A PUZZLE WORKOUT

## QUICKFIRE QUESTIONS

**Q1 Which disease was first successfully vaccinated against?**
- Bubonic plague
- Smallpox
- Spanish flu
- Common cold

**Q2 What did the Solar System evolve out of?**
- A black hole
- A supermassive star
- A solar nebula
- A mysterious monolith

**Q3 How much did the heaviest orca weigh?**
- Two tonnes
- Five tonnes
- Eight tonnes
- Ten tonnes

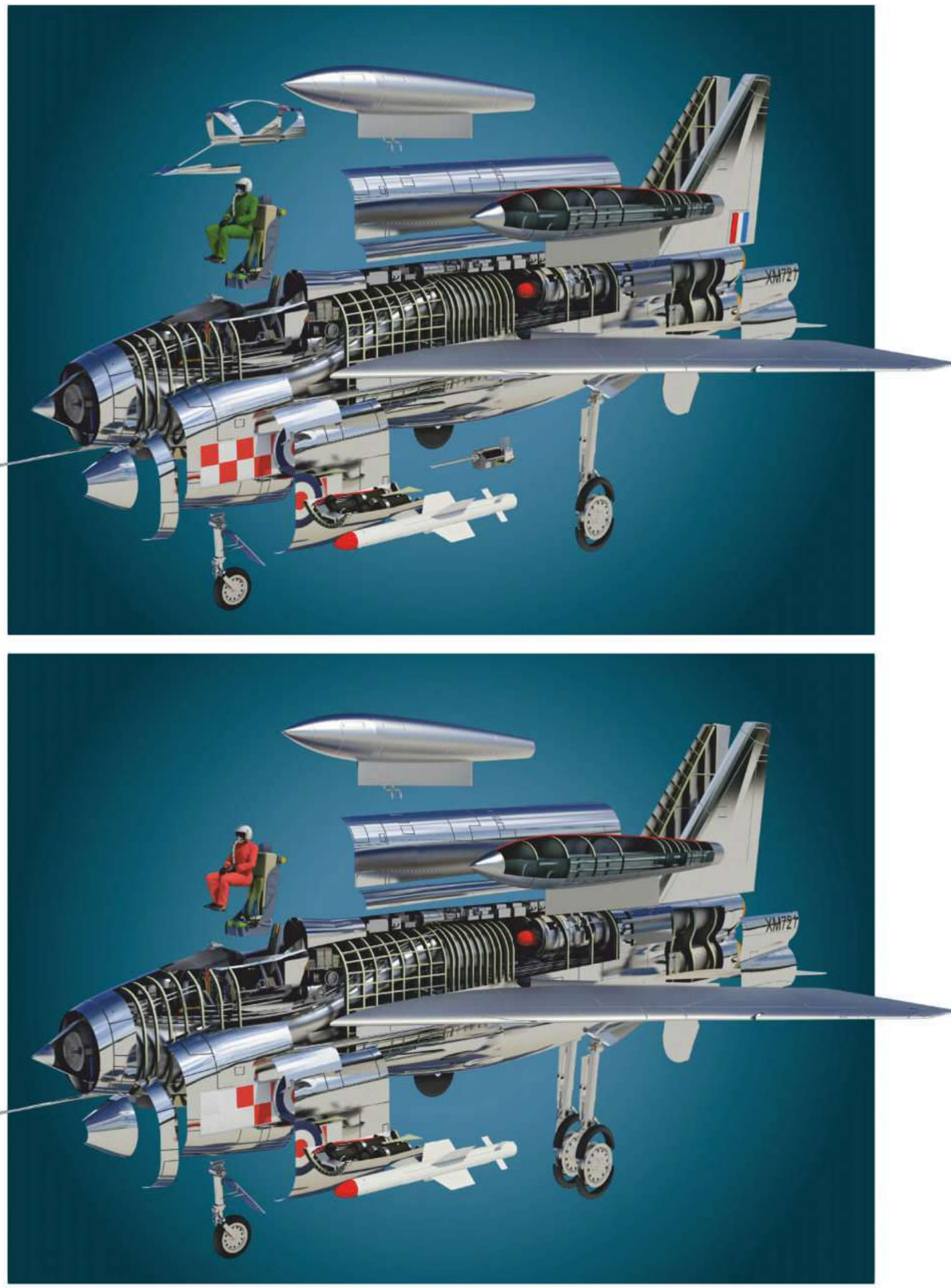
**Q4 What did the ancient Gauls of Western Europe use soap for?**
- Washing clothes
- Styling their hair
- Slippery weapons
- Cleaning foul mouths

**Q5 Technically, what is Ceres, the asteroid belt object?**
- An asteroid
- A star
- A moon
- A dwarf planet

**Q6 Who's known as the 'Father of Medicine'?**
- Hippocrates
- Socrates
- Archimedes
- Pythagoras

# Spot the difference

See if you can find all six changes between the images below



# Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9

**EASY**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 9 | 6 | | | | 2 |
| 1 | | | 8 | | 7 | | 3 | 6 |
| | 6 | 2 | | | 3 | | 9 | |
| | | | | 3 | | 7 | | |
| | 9 | 1 | 2 | | 4 | 8 | | 3 |
| 3 | | | 5 | 8 | 9 | 6 | 1 | |
| 2 | | | | 5 | 8 | | | |
| 9 | 7 | 5 | | 1 | 6 | | 4 | 8 |
| | | 8 | 7 | | 2 | | | 5 |

**DIFFICULT**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 2 | | 4 | 8 | | 7 | |
| | | 5 | | | | | | |
| | | | | 6 | | | 8 | |
| | | | 4 | | | | 3 | 2 |
| 3 | | | | 8 | | | | 9 |
| | | | 9 | | | 6 | | 5 |
| 8 | 2 | | | | | | 9 | |
| 4 | | 9 | | | | 3 | | |
| | | | | 9 | 2 | 4 | | 7 |

© Alamy

# What is it?

**Hint:** You can pull it...

**A** .....

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | V | I | T | S | L | C | O | B | O | A | S | M | A | D |
| M | E | S | A | O | K | X | E | Y | S | N | O | O | M | I |
| O | M | C | F | A | H | G | R | L | W | U | N | P | O | R |
| A | P | O | P | P | E | O | B | F | E | R | T | I | O | I |
| R | I | A | G | T | E | F | I | R | F | R | Q | U | C | P |
| O | R | D | L | T | A | O | O | N | E | S | A | C | J | H |
| N | E | W | E | M | P | L | S | H | O | P | I | R | N | O |
| T | A | M | V | O | J | F | I | R | E | O | X | C | A | N |
| G | E | L | D | I | B | A | C | T | O | M | S | I | R | E |
| E | M | B | I | P | Z | Y | I | O | F | C | I | Q | E | E |
| N | O | B | C | T | A | T | M | V | A | E | S | I | T | K |
| U | N | R | O | B | O | T | Y | B | I | C | K | G | S | R |
| H | U | S | B | O | Y | N | L | A | R | O | B | T | N | S |
| D | I | V | A | C | C | I | N | E | E | J | Q | C | O | Y |
| E | R | L | A | R | O | O | S | K | A | B | I | E | M | H |

# Wordsearch

***FIND THE FOLLOWING WORDS...***

ROBOT
METEOR
MONSTER
SCAB
MOONS
EMPIRE
FIRE
IPHONE
VACCINE
SOAP
CELERA
RONTGEN

# Check your answers

Find the solutions to last issue's puzzle pages

## SPOT THE DIFFERENCE

## QUICKFIRE QUESTIONS

**Q1** A giant impact
**Q2** Pyramids of Giza
**Q3** Crickets
**Q4** 2007
**Q5** Hydrogen
**Q6** 2 to 5 kilometres

## WHAT IS IT? ...A PIECE OF STRING

© Getty

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# HOW TO...

## Practical projects to try at home

### Get in touch

Send your ideas to...

- How It Works magazine
- howitworks@futurenet.com
- @HowItWorksmag
- howitworksmag

**HAD A GO? LET US KNOW!**

If you've tried out any of our experiments – or conducted some of your own – then let us know! Share your photos or videos with us on social media.

# How to make fake glass

With this realistic prop, you can safely perform breakaway stunts for home movies

### 1 Gather your ingredients

Into one large pot, you will need to add 450 grams of sugar, 256 millilitres of water, 128 grams of corn syrup and a quarter of a teaspoon of cream of tartar.

### 2 Stir your mixture

To produce an even pane of sugar glass, the ingredients need to be stirred for even distribution. Use a low-medium heat to avoid burning the sugar.

### 3 Boil off the water

If you have a thermometer, boil to 150 degrees Celsius. Otherwise keep to a medium heat. The water in the mixture will boil off to create a thicker, sugary substance that is ideal for moulding and shaping.

### 4 Prepare the pane

Line a baking tray with tin foil and spray it with some non-stick spray. This will make removing the glass easier, while the tray will hold the gloopy mixture, creating a rectangular mould for your window pane.

### 5 Carefully pour

Once the mixture thickens, pour the contents onto the tray to fill the entire rectangle. Be careful: the pot and its contents will be very hot. You might see bubbles at the surface, but these will disappear as the sugar glass hardens.

### 6 Watch it solidify

Next you will need to wait while it cools. You can either leave it at room temperature for around two hours, or for quicker results place it in the fridge. Keep the sheet cold until you plan on using it.

### 7 Smash it!

Remove the foil to see your result. After you've admired your glass-like pane, you're ready to perform your stunt. It might be best to take your movie set outside, as this is bound to make a shattered mess.


**SUMMARY**

Sugar glass is a common choice for those who want to create epic stunts without risking injury to those acting. Producing the glass this way means that the thickness and colour can be altered for a range of effects and resistance. It's also inexpensive and easily available, making it great for the many takes that might need to be shot.

The acidic cream of tartar is a crucial ingredient, as it stops crystalline structures from forming within sugar when it's cooked at high temperatures. Without this, the transparency won't be achieved.


**NEXT ISSUE...** Make your own speaker system


© Illustrations by Ed Crooks

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# INBOX

## Speak your mind...

© Getty

Mirrors were invented almost 200 years ago

## Mirror mirror

Dear **HIW,**

I just learned that my mum has subscribed to **How It Works** as my birthday gift. I'm looking forward to receiving the first copy. Hope it doesn't take too long to fly from the UK to Australia! I understand that white objects look white because they reflect back all the colours/visible light waves? Do mirrors reflect all visible light? If so, why don't they look white? Thanks a lot!

**Albert, age 10**

**Great question Albert! Both white objects and mirrors reflect all visible wavelengths in the electromagnetic spectrum. The difference is that white objects scatter the light in many different directions, while more of the light bounces off mirrors in the same direction it came from. The polished silver or aluminium on one side of the glass is ultra smooth at a microscopic level, reflecting more light back in the direction it came from than the relatively rough surface of a white object. We hope you enjoy your first issue of the magazine and keep asking questions about science.**

## Get in touch

If you have any questions or comments for us, send them to:

How It Works magazine @HowItWorksmag

howitworks@futurenet.com howitworksmag

## Letter of the month

# Exercise your eyes

Dear **HIW,**

What would happen if people that are doing virtual learning don't take care of their eyes? Maybe you should put some eye exercises in **How It Works** magazine and explain how eyes work and why you need to protect them.

**Rosie Lee**

**Many people will be in the same position as you at the moment, spending an increased amount of time looking at screens as they attempt to stay connected from their homes. Looking at a bright screen for extended periods of time can cause eye strain, so it is beneficial to know how to give your eyes a break.**

**Eye strain occurs because while you focus on a screen, you tend to blink less, which can dry out your eyes. This can create blurry vision and discomfort. Alongside this, if you focus on a screen for hours every day, your eyes can get used to focusing on near objects and struggle to see things in the distance. Here are three tips that you and other readers who wish to reduce the impact of screen time can use:**

**1 Try the 20-20-20 rule. While you are doing your classes online, take regular short screen breaks. Every 20 minutes, make sure to focus on something that's around six metres – or 20 feet – away from you for at least 20 seconds.**

**2 Flex your eye muscles from time to time and concentrate on blinking. When you take a break, look up, down, left and right ten times without moving your head. Then try to blink every five seconds for around two minutes.**

**3 Palming can help to soothe your eyes. This technique involves placing the palms of your hands over your eyes. Don't put too much pressure on them. Make sure you can still blink freely. With your palms resting on your cheekbones, after two minutes your eyes should feel more relaxed.**

© Getty

When looking at screens, we blink around half as much as usual


**WIN! A HAYNES MANUAL**

From cars, to skyscrapers, to galaxies and even the Millennium Falcon: Haynes guides take all sorts of things apart, show the reader exactly how they work, and how to repair and maintain them.

© Haynes

These impacts come into play after long-term large-scale farming of solar and wind power

© Getty

## Turbine trouble

Dear **HIW,**

What are the long-term consequences, through the increased use of solar and wind farms, to Earth's weather patterns?

**John**

**Big wind farms have been shown to alter the air temperature near the ground. As turbines churn the air, temperatures rise in the night and fall during the day. Long-term, it's thought that large-scale wind farming will warm the atmosphere, but will be better for the environment than using fossil fuels. One study showed that if a third of the US was covered in enough wind turbines to meet its electricity demand, the surface temperature there would rise by 0.24 degrees Celsius by the end of the century.**

**Solar panels can also cause slight warming, as blocking the Sun's radiation from hitting large areas of the ground first cools the ground. This change impacts local weather patterns, resulting in reduced rainfall, causing an increase in temperature.**

# PC components

Dear **HIW,**

I read **How It Works** magazine right after it's delivered. I love learning new things. I have a question that I couldn't figure out by myself. What's inside a computer that makes it save files and download games?

**Rosie**

Magnetised or unmagnetised 'bits' are written as ones and zeros

**Inside a computer there's a drive for storing data. Each tiny piece of information is called a 'bit', and eight make up a 'byte'. Information from your file or game can be read and arranged in binary code, stored as bits and bytes of data. A complex code is created as the bits align in the disk when data is saved, and this code will remain when you switch off your computer. As this drive in your computer is read when you load up a file, each code corresponds to a different element of the file. When these combine, specific qualities emerge. Modern drives are usually solid-state drives (SSD), which have replaced slower hard disk drive (HDD) technology.**

# Allergic to the Sun?

Dear **HIW,**

Can you tell me why I sneeze when I look into the Sun?

**William Sentance, Age 9**

**This is a question that even scientists haven't entirely sussed out yet. But it is a common reaction for many people. You aren't allergic to the Sun's rays: this is a physiological response known as photic sneezing. The main theory as to why this happens is down to a specific nerve in our heads, called the trigeminal nerve. This complex nerve sits next to your optic nerve, the nerve which sends information from your eyes to your brain. Detecting the brighter light, it is thought that the impulse sent through the optic nerve is picked up by your trigeminal nerve. This is then felt as a tickle in the nose, which can sometimes make you sneeze.**

18 to 35 per cent of people are known to have the photic sneeze reflex

## What's happening on... social media?

**This month on social media we asked you: 'What technological advancements or inventions would you like to see in 2021?'**

**@wtorrell1**
*Zero-emission commercially available planes*

**@louistyndall**
*An underground system that charges electric cars as they drive on the road*

**@cathode149**
*Biodegradable phones*

**@_rchiesw_in**
*Phones with built-in solar panels*

**Thomas Flanagan**
*I still think that a mobile phone could do with an in-built laser to light a cigarette! (Although I don't smoke)*

**@jack_macneilly**
*Interplanetary travel*

**@scimaxfacts**
*Flying cars would be cool to see in the near future!*

## NEXT ISSUE...

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# FAST FACTS

## Amazing trivia to blow your mind

**50**

**DOZENS OF FISH SPECIES CAN BE FOUND IN UK ROCK POOLS AT LOW TIDE**

**222 MILLION**

**AS OF FEBRUARY 2020, THE iPHONE 6/6 PLUS IS APPLE'S BEST-SELLING SMARTPHONE**

**3,000**

WHALE SHARKS HAVE THOUSANDS OF TEETH... ON THEIR EYEBALLS

**5 BILLION**

YOU COULD FIT BILLIONS OF SUNS INSIDE HYPERGIANT STAR UY SCUTI

**8 TONNES**

16 CUBIC CENTIMETRES OF HUMAN BONE CAN BEAR HUGE LOADS

**BABIES HAVE AROUND 100 MORE BONES THAN ADULTS**

**FROZEN SOAP BUBBLES CAN PRODUCE A STUNNING SNOW GLOBE EFFECT**

**300 BILLION**

OUR LUNGS ARE PACKED WITH TINY CAPILLARIES

**3,785 LITRES**

**A FIRE ENGINE'S PRIMARY WATER TANK CAN HOLD AS MUCH WATER AS A LARGE POND**

**1959**

AN APRIL FOOL'S JOKE THAT MARS' TWO MOONS WERE ARTIFICIAL SATELLITES GAINED WORLDWIDE ATTENTION IN THIS YEAR

**SPACEX BOSS ELON MUSK HOPES TO POPULATE MARS WITH A MILLION PEOPLE BY 2050**

★★★★★

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